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Bulletin 716

CONTRIBUTIONS TO ECONOMIC GEOLOGY

(SHORT PAPERS AND PRELIMINARY REPORTS)

1920

PART II.—MINERAL FUELS

DAVID WHITE AND M. R. CAMPBELL

GEOLOGISTS IN CHARGE



WASHINGTON

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CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1920.

PART II. MINERAL FUELS.

DAVID WHITE and M. R. CAMPBELL, *Geologists in charge.*

INTRODUCTION.

The Survey's "Contributions to economic geology" have been published annually since 1902. In 1906 the increase in the number of papers coming under this classification made it necessary to divide the contributions into two parts, one including papers on metals and nonmetals except fuels and the other including papers on mineral fuels. In 1915 the year included in the title was changed from the year in which the field work reported in these papers was done to the year of publication, and in consequence there was no volume entitled "Contributions to economic geology, 1914." The subjoined table gives a summary of these bulletins.

United States Geological Survey "Contributions to economic geology."

Date in title.	Date of publication. ^a	Bulletin No.	Date in title.	Date of publication. ^a	Bulletin No.
1902.....	1903	213	1912, Part I.....	1914	540
1903.....	1904	225	1912, Part II.....	1914	541
1904.....	1905	260	1913, Part I.....	1915	580
1905.....	1906	285	1913, Part II.....	1915	581
1906, Part I.....	1907	315	1915, Part I.....	1916	620
1906, Part II.....	1907	316	1915, Part II.....	1916	621
1907, Part I.....	1908	340	1916, Part I.....	1917	640
1907, Part II.....	1909	341	1916, Part II.....	1917	641
1908, Part I.....	1909	380	1917, Part I.....	1918	660
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1911, Part I.....	1913	530	1920, Part I.....	1921	715
1911, Part II.....	1913	531	1920, Part II.....	1921	716

^a The date given is that of the complete volume; beginning with Bulletin 285, the papers have been issued as advance chapters as soon as they were ready.

As the subtitle indicates, most of the papers in these volumes are of three classes—(1) short papers describing as thoroughly as conditions will permit areas or deposits on which no other report is

likely to be prepared; (2) brief notes on mining districts or economic deposits whose examination has been merely incidental to other work; and (3) preliminary reports on economic investigations the results of which are to be published later in more detailed form.

Although these papers set forth mainly the practical results of economic investigations they include brief theoretical discussions and summary statements of conclusions if these appear to require prompt publication.



DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

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Bulletin 716—A

GEOLOGY OF ALAMOSA CREEK VALLEY SOCORRO COUNTY, NEW MEXICO

WITH SPECIAL REFERENCE TO THE
OCCURRENCE OF OIL AND GAS

BY

DEAN E. WINCHESTER

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(Pages 1-15)

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NOTE.—The Survey's annual volumes entitled "Contributions to economic geology" are issued in parts, and the last part will include a volume title-page, table of contents, and index for the use of those who may wish to bind the separate parts. A small edition of the bound volume will also be issued, but copies can not be supplied to those who have received all the parts.

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GEOLOGY OF ALAMOSA CREEK VALLEY, SOCORRO COUNTY, NEW MEXICO, WITH SPECIAL REFERENCE TO THE OCCUR- RENCE OF OIL AND GAS.

By DEAN E. WINCHESTER.

INTRODUCTION.

During a detailed study of the coal resources of a part of northern Socorro County, N. Mex., made in 1913 and 1914, considerable information relative to the stratigraphy and structure of the region was collected. Recent interest in the oil and gas possibilities of New Mexico makes it desirable to record the observations made, so that they may serve as a guide in the search for petroleum and natural gas.

FIELD WORK.

In the field examination the writer was assisted by Heath M. Robinson, W. T. Thom, jr., S. D. Greene, and Delbert Williams, each of whom took an active part in the collection of the information.

Geographic as well as geologic features were mapped in the field on a scale of 2 inches to the mile, and the accompanying map (Pl. V) is the result of the compilation of this information. The rock beds are folded and faulted and are intruded by igneous rocks, and considerable time was spent in the study of the structure. Much time was also given to measuring stratigraphic sections and to collecting fossils upon which to base correlations. Many large collections of invertebrate and plant fossils were made in the field and have been studied by T. W. Stanton and F. H. Knowlton. All surveys were tied to section corners either by stadia traverse or by direct triangulation. A careful study of the chemical analyses of the coals of this region furnishes suggestions concerning the possibility of the presence of petroleum and natural gas in the formations of the region.

GEOGRAPHY.

Location and extent.—The valley of Alamosa Creek covers an area of approximately 600 square miles, mostly in Socorro County, N. Mex. It lies north of the Bear, Gallina, and Datil mountains, between the Sierra Ladron on the east and the Continental Divide on the west, and extends northward as far as the north line of T. 4 N.

Surface features.—The valley is bounded on the south and east by low rugged mountains. The Bear Mountain range, to the southeast,

consists of a large number of peaks, the highest of which are more than 7,600 feet above sea level. The Tertiary bedded volcanic rocks, sandstones, and conglomerates of the Datil formation, which make up these mountains, have been dissected into innumerable conical peaks and present an entirely different landscape from that shown in the Sierra Ladron, which lies a short distance east of the area shown on Plate V.

Between the Bear Mountains and the Gallina Mountains, to the west, there is a comparatively broad area which is deeply dissected by small streams that flow into Alamosa Creek. The Gallina Mountains, like the Bear Mountains, consist of the Tertiary rocks, which have been dissected into innumerable conical peaks having altitudes of 9,000 to 9,500 feet above sea level.

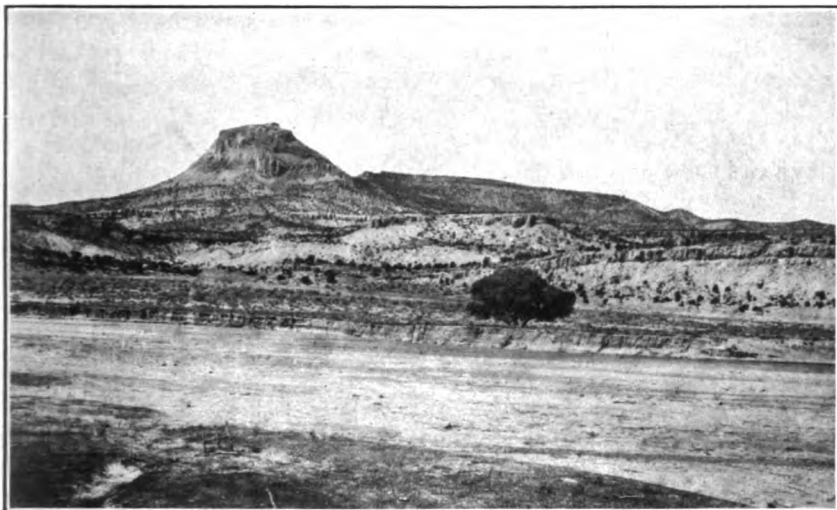
The Datil Mountains, west of the Gallina Mountains, are the highest and most rugged mountains in the area mapped. Like the Gallina and Bear mountains, they comprise a large number of high peaks carved from rocks of the Datil formation. Several of the higher peaks rise more than 9,600 feet above sea level. The east-west series of peaks shown on the map forms only a small part of the Datil Mountains. These mountains are clothed with pine timber, a considerable part of which is large enough to be of economic importance.

These three mountain ranges are separated from one another by comparatively low divides. That between the Bear and Gallina mountains is the lowest and accommodates the only wagon road by which the field may be entered from the south.

To the north of the main mountain ranges there are several high peaks which are locally designated mountains. D Cross Mountain (Pl. I, A), the highest of these peaks, is an igneous plug 2 miles north of Alamosa Creek, in the western part of T. 3 N., R. 8 W. It rises about 2,000 feet above the level of the creek, or 8,775 feet above sea level.

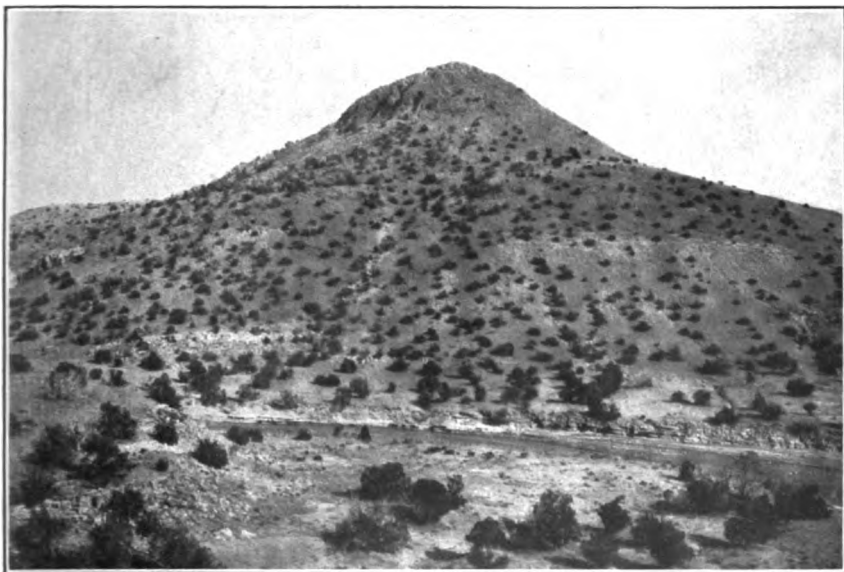
On the divide between Alamosa Creek and Miguel Canyon, 2 miles to the west of D Cross Mountain, is Bell Mountain, an igneous intrusive mass which rises to an altitude only a little lower than that of D Cross Mountain. Broom Mountain, 3 miles north of the area mapped, on the line between Rs. 7 and 8, is a flat-topped landmark capped by sandstones of Cretaceous age and stands about 8,400 feet above sea level.

Less conspicuous buttes in several parts of the field reach altitudes 200 feet or more above the general level of the surrounding area. Three of the most noted of these are the Tres Hermanos Buttes, in sec. 28, T. 3 N., R. 7 W. These buttes are formed of igneous rock which has been forced up into the Cretaceous strata. La Cruz Peak (Pl. I, B), in sec. 13, T. 2 N., R. 6 W., about 6,975 feet above sea level, and La Jara, in sec. 11, T. 2 N., R. 5 W., about 6,875 feet above sea



A. D CROSS MOUNTAIN, SOCORRO COUNTY, N. MEX.

Gallego sandstone member and one of the sandstones of the lower part of the Miguel formation shown in the foreground.



B. LA CRUZ PEAK, SOCORRO COUNTY, N. MEX.

A basalt plug.



CROSS-BEDDED SANDSTONE OF THE "RED BEDS" AT OJO DE LOS CHUPADEROS, IN SEC. 12, T. 2 N., R. 6 W.,
SOCORRO COUNTY, N. MEX.

level, are particularly good examples of volcanic necks which form prominent and well-known landmarks of the region. Innumerable small buttes or points formed by the unequal erosion of sedimentary rocks, gravels, etc., may be seen within the area described. The several steep-sided lava-capped mesas that rise abruptly above the surrounding country are in most places clothed with a good growth of grass and some scrub timber. Such mesas are conspicuous north and south of the Tres Hermanos Buttes, in Tps. 2, 3, and 4 N., R. 7 W., and north of Miguel Canyon, in T. 4 N., Rs. 8 and 9 W.

Within this area there are also a large number of ridges and hogbacks caused by resistant sandstones of the Miguel formation that dip at low angles. West of the little Mexican town of Puertecito successively higher beds of sandstone dipping at low angles to the westward give rise to several hogbacks. In the vicinity of the Chavez ranch, in T. 1 N., R. 5 W., and north of La Cruz Peak, the rocks have been faulted and tilted so that there are four or more parallel hogbacks, each capped by sandstone of the same bed.

Alamosa Creek contains running water at a great many places throughout the year, and in most places where the bed of the stream appears dry, water may be found within a foot or so of the surface. In time of rains the stream is sometimes impassable.

Springs of good water issue from the sandstones of the region and have determined to a large extent the location of the ranches. In addition to the numerous small springs, the following are of note:

Ojo Alamo, in sec. 13, T. 2 N., R. 6 W.

Ojo de los Barrancos, in sec. 12, T. 2 N., R. 5 W.

Ojo de los Chupaderos, in sec. 2, T. 2 N., R. 5 W.

Abbey Springs, in sec. 8, T. 1 N., R. 5 W.

Jara Spring, in sec. 15, T. 2 N., R. 5 W.

Tres Hermanos Spring, in sec. 24, T. 3 N., R. 7 W.

Navajo Spring, in sec. 17, T. 3 N., R. 7 W.

I. N. M. Spring, on the south bank of Alamosa Creek in the NW. $\frac{1}{4}$ sec. 28, T. 3 N., R. 8 W.

Box Bar Springs, a small spring on the Box Bar ranch, in sec. 4, T. 2 N., R. 9 W.

The water is appropriated largely for domestic purposes.

Los Terros, in sec. 1, T. 2 N., R. 10 W.

Miguel Spring, in sec. 33, T. 4 N., R. 9 W.

Cacho Springs, near Bodenheimer's ranch, in sec. 10, T. 4 N., R. 9 W.

Culture.—Several large cattle ranches in the western part of the field are owned by Americans, but the area east and south of Puertecito is occupied almost entirely by smaller ranches owned by Mexicans. In the vicinity of Ojo Alamo, in T. 2 N., R. 6 W., there is a small colony of Navajo Indians, whose chief occupation is the raising of small bands of goats and sheep. The region is not suited to cultivation and will therefore probably continue to be used largely for stock raising.

Puertecito, in sec. 29, T. 3 N., R. 5 W., is a small Mexican village composed of about a dozen adobe houses ranged along an east-west street. The town is the headquarters of a considerable Mexican and Indian trade and supports two small tiendas, or stores.

At present Burley is the only post office within the area. During the summer of 1913 this office was at a ranch on Felipe Gilbert Creek, in sec. 10, T. 2 N., R. 7 W., but at the end of the season it was moved to the I. N. M. ranch, on Alamosa Creek, in sec. 21, T. 3 N., R. 8 W. Since that time the post office has been again moved, so that it is now only 10 miles west of Puertecito. Mail is brought by stage from Magdalena, a distance of about 50 miles, twice a week. Magdalena, with 3,000 inhabitants, the nearest railroad town, is at the end of a spur of the Atchison, Topeka & Santa Fe Railway about 20 miles southeast of the area mapped and is the shipping point for stock from this area as well as a much larger area to the south and west.

Because of the extremely rough topography, wagon roads have been laid out along the valleys and in many places are very crooked as well as rough.

Climate and vegetation.—The field is in the arid region of the Southwest, and its climate is typical of that region. Rain usually comes in torrents, and therefore the run-off is great and erosion due to running water is very rapid.

GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES.

The sedimentary rocks exposed within the area here described have a maximum thickness of about 8,000 feet and range in age from Carboniferous to Recent. The red clays and sandstones of the Triassic are overlain unconformably by Cretaceous sandstones and shales, the oldest of which is correlated with the Dakota sandstone. The Dakota is overlain by a series of shales and sandstones having an aggregate thickness of about 3,700 feet. This series is subdivided into two formations, the lower of which is here named the Miguel formation and the upper of which is here named the Chamiso formation. Unconformably overlying these Cretaceous sediments is a formation consisting of a series of tuffs, rhyolites, sandstones, and conglomerates, which is probably of late Tertiary age, although no fossils were found that lend evidence for this assumption. This formation is here named the Datil formation because it is the mountain-forming series of the Datil Mountains, along the southern margin of the field. Quaternary unconsolidated gravels and alluvium occur in small areas. The following table shows the character and relations of the sedimentary formations of the field:

Generalized section of the rocks exposed in Alamosa Valley, N. Mex.

System.	Formation.	Character of rocks.	Thickness (feet).
Quaternary.	Alluvium.	Valley filling.	20±
	Gravels.	Well-rounded and sorted pebbles.	25±
Tertiary.	Datil formation.	Well-indurated tuffs, rhyolites, cross-bedded sandstones, and conglomerates. Members are extremely variable.	2,000±
	Unconformity		
Cretaceous.	Chamiso formation.	Soft yellow sandstones and sandy shales, with intercalated carbonaceous beds. Contains abundant fossil leaves. Coal beds at three general horizons, but the one about 75 feet above the base is the only bed of importance.	1,860
	Miguel formation.	Yellow sandstones, drab and yellow sandy shales with a few beds of clay and several beds of coal in upper half. Abundant invertebrate fossils and a few plant remains. This formation contains four persistent massive yellow sandstone members, two of which are here named, the name Bell Mountain sandstone member being applied to the one at the top and Gallego sandstone member to the one near the middle.	2,080
	Dakota sandstone.	Quartzose gray to brown sandstone which in places contains pebbles and fragments of underlying sandstones. Contains a few plant remains.	0-40
	Unconformity, erosional and angular		
Triassic and Carboniferous.	"Red Beds."	Red argillaceous shale, interbedded with thin beds of lavender sandstone; at base thin conglomerate containing chert pebbles.	600+
		Limestone and gypsum beds, base not exposed.	300+

CARBONIFEROUS AND TRIASSIC ROCKS ("RED BEDS").

The basal part of the section as exposed in the Alamosa Valley is composed of sediments which are predominantly red and include a great thickness of red, vermilion, and lavender clay shales, coarse cross-bedded sandstones (see Pl. II), and thin beds of conglomerate, with some limestone and gypsum in the lower part. In some places there is, about 600 feet below the top of the series, a thin bed of conglomerate which may represent the Shinarump conglomerate of northwestern New Mexico and northeastern Arizona. No fossils were found upon which to make a correlation, but from the lithology it is assumed that the beds above the conglomerate are Triassic and that those below may belong to the Manzano group, of Permian age.

CRETACEOUS ROCKS.

DAKOTA SANDSTONE.

Resting unconformably on the "Red Beds" just described is a sandstone ranging in thickness from 0 to 40 feet, which is correlated with the Dakota sandstone of other areas on the basis of its fossil

flora; lithology, and stratigraphic position. In some places this sandstone is almost a pure quartzite; in others it is very conglomeratic; but in most places it is simply a coarse well-cemented ferruginous sandstone which contains a few pebbles as large as half an inch in diameter. Along the west side of the Red Lake fault the sandstone is thin and in places entirely absent.

MIGUEL FORMATION.

In this field the 3,900 feet of Cretaceous rocks that occur above the Dakota sandstone are subdivided into the Miguel and Chamiso formations, on the basis of their lithology and fossil content. The lower half of the series, here named the Miguel formation, from Miguel Creek, which crosses the beds in the northwestern part of the area, is composed of a succession of massive persistent sandstones, soft sandstones, and dark shales with coal, which contains an abundant Benton (early Colorado) fauna throughout and a sparse flora that F. H. Knowlton regards as probably of Montana age. These beds have the stratigraphic position of a large part of the Mancos shale but are lithologically quite different, being chiefly sandstone, whereas the Mancos in its type locality is almost entirely shale. According to the invertebrates it contains the Miguel is entirely of Colorado age, but the Mancos includes beds of Montana age in addition to those representing the whole Colorado group. For these reasons the local name Miguel formation is here introduced.

The upper portion of the series, here named the Chamiso formation, from Chamiso Creek, in T. 2 N., R. 9 W., is composed of soft sandstones and sandy shales containing an abundant Montana (Mesaverde) flora but no invertebrates, and is wholly of nonmarine origin; the Mesaverde formation, which is in part equivalent, consists of alternating beds of marine and nonmarine origin.

The Miguel formation includes four thick resistant and persistent beds of sandstone. The two lower may represent the Tres Hermanos sandstone of Lee,¹ but they are the least conspicuous of the sandstones of this area and were therefore not mapped. They are exposed a mile east of the Tres Hermanos Buttes. The Gallego sandstone member, named from Gallego Creek, occurs near the middle of the formation and is well exposed in Pueblo Viejo (Pl. III, A), a small mesa in sec. 17, T. 4 N., R. 7 W., which was once used as a stronghold by a small group of Indians. It is also exposed on the south and east sides of the Tres Hermanos Buttes, near the base of the buttes. This sandstone occurs about 900 feet above the Dakota and ranges in thickness from 50 to 90 feet. The Bell Mountain sandstone member (see Pl. III, B), which is well exposed near the foot of Bell Mountain, in T. 3 N., R. 9 W., is at the top of the Miguel formation and is about 80 feet thick.

¹ Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, pp. 27-58, 1913.

A section of the Miguel formation was measured in the gap south of D Cross Mountain as follows:

Section of Miguel formation 2 miles west of I. N. M. ranch.

Sandstone, thick bedded, yellow to gray, coarse; <i>Halymenites</i> at the top, <i>Inoceramus</i> at the base (Bell Mountain sandstone member).....	Feet. 79
Shale, greenish and drab, fissile, containing hard brown concretions near the top; fossil shells 10 feet below the top.....	175
Sandstone, brown, hard.....	2
Sandstone, yellow, shaly, slightly carbonaceous at the base.....	34
Shale, yellow to drab, with thin beds of sandstone.....	35
Sandstone, brown, hard, coarse.....	1
Sandstone, yellow, massive.....	25
Shale, yellow and drab, with thin beds of sandstone.....	584
Sandstone, yellow, and dark to yellow shale, with 10 feet of carbonaceous shale at the top.....	80
Sandstone, yellow, thin bedded, and drab shale, sandy at the top, carbonaceous below, containing leaf fragments and 6 inches of coal near the top.....	47
Sandstone, yellow, massive, containing <i>Halymenites</i> (Gallego sandstone member).....	93
Sandstone and shale, mostly covered.....	380
Sandstone, yellowish, massive, coarse, gray; fossil shells, 20 feet above the base.....	78
Sandstone and shale.....	6
Shale, yellowish gray and drab, fissile.....	134
Covered.....	50
Sandstone, with gastropods.....	15
Shale, drab, with oysters and shark teeth.....	50
Sandstone, yellowish gray, conglomeratic and cross-bedded.....	23
Shale, drab, argillaceous, with oysters 10 feet below the top.....	82
Covered, mostly shale.....	109
Dakota sandstone.....	
	2,082

Section of lower part of Miguel formation south of Puertecito, N. Mex.

Miguel formation:	Feet.
Sandstone, thin bedded.....	5
Shale, sandy.....	75
Sandstone, shaly; fossil shells.....	3
Sandstone, yellow, massive.... } Gallego sandstone member {	43
Sandstone, friable..... }	17
Covered but composed of drab shale at top; fossil shells at top.	87
Sandstone.....	5
Shale, sandy.....	25
Sandstone.....	10
Shale.....	50
Sandstone.....	5
Shale; fossil shells.....	9
Sandstone, yellow, thin bedded.....	42
Shale and sandstone, shaly.....	52
Sandstone; fossil shells.....	10
Shale and sandstone, shaly.....	136
Sandstone, heavy bedded, yellow.....	75

Miguel formation—Continued.		Feet.
Shale, light to slate-colored.....		90
Shale and sandstone, calcareous.....		35
Sandstone, thin bedded, brown, calcareous.....		10
Shale, largely covered.....		40
		824
Dakota sandstone:		
Sandstone, massive, angular grains.....		26
Sandstone, gray, thin bedded.....		5

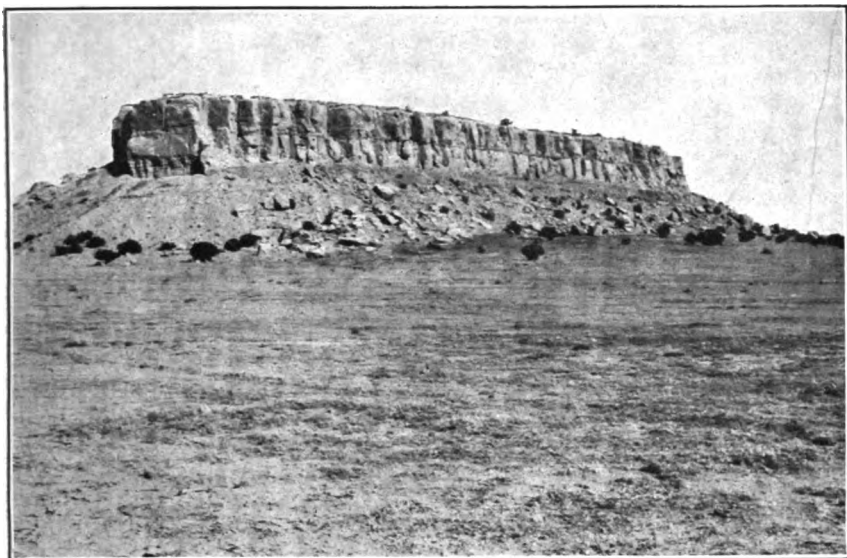
CHAMISO FORMATION.

Above the Bell Mountain sandstone, which marks the top of the Miguel formation, is a series of yellow sandstones, sandy shales, and coal beds that contains no persistent indurated beds like the underlying formation. This series on the basis of the fossil leaves which it contains might be correlated with the Mesaverde formation, but its lithologic character is quite different from that of the Mesaverde in its type locality; the deposits are wholly of nonmarine origin, whereas the Mesaverde consists of alternating marine and nonmarine sediments; and as the underlying beds (Miguel formation) are all of Colorado age, while the typical Mesaverde is underlain by beds of early Montana age, it is probable that rocks older than the typical Mesaverde are included in this series. The local name Chamiso formation is therefore introduced, from Chamiso Creek, in T. 2 N., R. 9 W.

One of the best coal beds in the field occurs about 75 feet above the base of the Chamiso and is extensively exposed west and northwest of D Cross Mountain. Other zones of carbonaceous material are present at several horizons in the formation, but none are of more than local importance. About 1,300 feet above the base there is a carbonaceous zone which contains coal in several places. The thickest coal bed is exposed in Red Canyon 3 or 4 miles south of the Box Bar ranch. The following detailed section was measured in the north side of Blue Mesa and shows the general character of the formation:

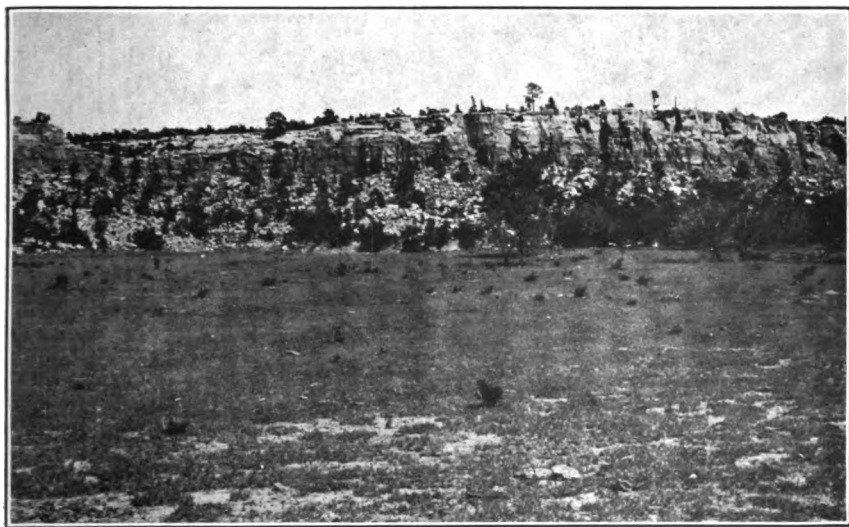
Section of Chamiso formation north of Blue Mesa, in T. 2 N., R. 8 W.

	Feet.
Sandstone, yellow to greenish, soft, and shale, sandy, yellow to green.	440
Sandstone, gray, coarse.....	4
Coal and carbonaceous shale.....	1½
Shale, and sandstone, soft.....	46
Coal and carbonaceous shale.....	2
Shale.....	20
Shale, yellow, and sandstone, thin bedded.....	175
Sandstone, massive, yellow, cross-bedded.....	30
Shale, greenish yellow and drab, argillaceous; fossils.....	50
Shale and sandstone.....	145

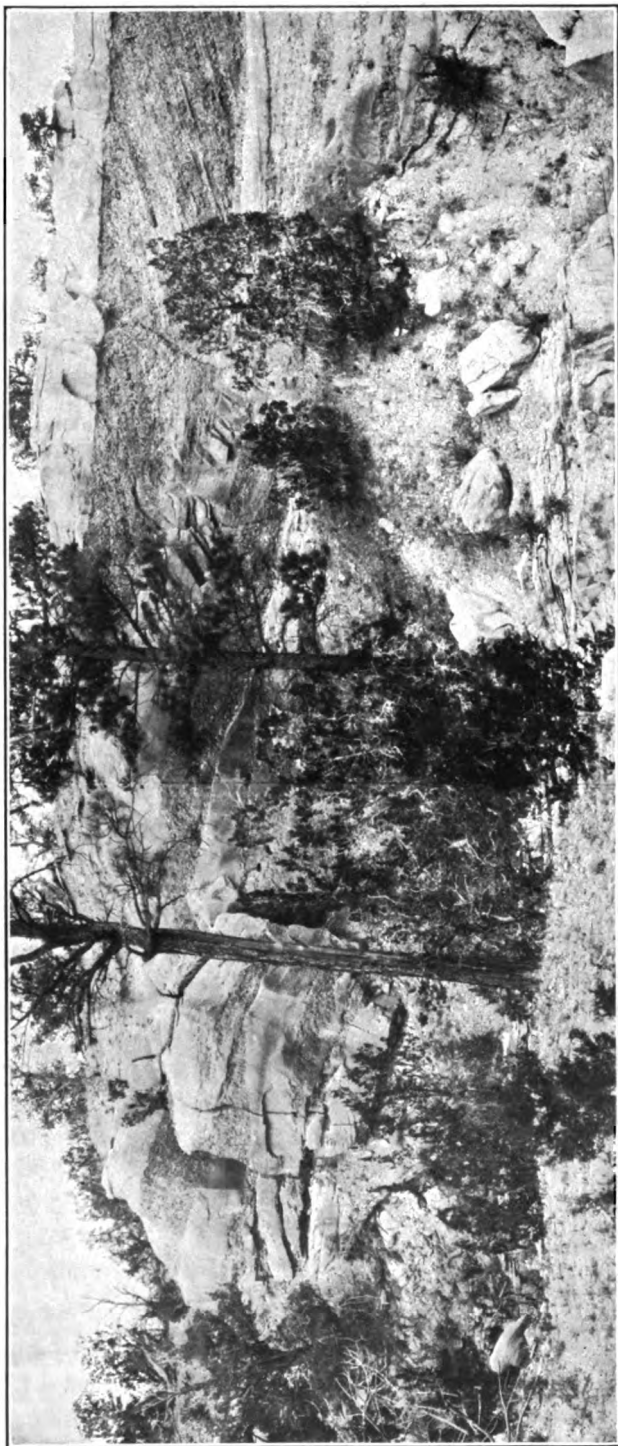


A. PUEBLO VIEJO, SOCORRO COUNTY, N. MEX.

A typical development of the Gallego sandstone member of the Miguel formation.



B. BELL MOUNTAIN SANDSTONE MEMBER OF MIGUEL FORMATION AT FOOT OF BELL MOUNTAIN, SOCORRO COUNTY, N. MEX.



DATIL FORMATION (CONGLOMERATE AND SANDSTONE) IN ALAMOSA CREEK VALLEY, N. MEX.

	Feet.
Sandstone, coarse, massive.....	25
Sandstone, gray, thin bedded, with thin beds of indurated brown sandstone.....	205
Sandstone, yellow, massive, coarse.....	3
Shale, yellow and drab, sandy.....	20
Sandstone, gray, soft, thin bedded.....	15
Shale, carbonaceous at the top.....	25
Shale and sandstone, with beds of hard brown concretions.....	128
Sandstone.....	4
Sandstone, thin bedded; fossils.....	5
Covered.....	108
Sandstone, yellow to brown, coarse.....	7
Sandstone, thin bedded, and shale.....	100
Shale, drab.....	50
Sandstone, thin bedded to shaly.....	97
Sandstone, yellowish gray, coarse.....	5
Sandstone, yellow, coarse, soft, thin bedded.....	108
Sandstone, massive (Bell Mountain member of Miguel formation).....	1,809½

Section of part of Chamiso formation in Triangulation Butte, northwest of Box Bar ranch, in sec. 31, T. 3 N., R. 9 W.

	Feet.
Sandstone, yellow, cross-bedded.....	25
Shale, sandy, and sandstone, soft.....	10
Sandstone, yellow, coarse.....	27
Shale.....	14
Sandstone, yellow.....	2
Shale.....	2
Coal.....	½
Shale, light drab.....	10
Sandstone, yellow; fossils.....	20
Shale, greenish yellow, concretionary.....	9
Sandstone, greenish yellow.....	2
Shale, greenish gray to drab.....	55
Sandstone, yellow, coarse; fossils.....	5
Sandstone, friable.....	30
Sandstone, yellow, coarse; fossils.....	8
Shale.....	219½

TERTIARY ROCKS.

DATIL FORMATION.

Resting unconformably upon the older formations and giving rise to rugged mountainous topography is a series of tuffs, rhyolites, conglomerates, and sandstones, which so far as known contain no fossils. Their age is regarded as probably late Tertiary, but more definite correlation is impossible. At most places the beds of this formation are practically horizontal, but none of the members are persistent, cross-bedding and steep depositional angles being common. (See Pl. IV.)

The following section was measured at the north end of the Bear Mountains near the east boundary of the field and illustrates the general character of the formation:

Section of the Datil formation at the north end of the Bear Mountains.

	Feet.
Quartz rhyolite.....	120
Conglomerate and sandstone, reddish, friable, Conglomerate contains angular fragments of igneous rock.....	40
Sandstone.....	35
Conglomerate with pebbles as large as 1 foot in diameter.....	50
Sandstone and conglomerate in alternating beds.....	25
Sandstone, argillaceous.....	4
Tuff, conglomeratic, with pebbles and angular fragments as much as 18 inches in diameter.....	60
Rhyolite, vitreous, light colored.....	4
Andesite, light purple, vesicular.....	8
Agglomerate with igneous pebbles as much as 1 foot in diameter....	17
Tuff, similar in composition to 65-foot bed below but gray and rather porous and slightly more basic.....	105
Tuff, red, compact, with groundmass of glass, iron ore, feldspar, and secondary calcite; inclusions of glassy material containing phenocrysts of feldspar, biotite, and iron ore.....	65
Sandstone, friable, containing earthy material.....	127
Covered.....	60
Tuff, conglomeratic, dark, slate-colored; angular fragments of igneous rock; maximum diameter of rounded pebbles 18 inches....	420
Sandstone, red, argillaceous; contains streaks of gypsum.....	210
Covered but contains some yellow sand.....	190
Conglomerate like 4-foot bed below.....	5
Sandstone, thin bedded, with clay.....	1½
Clay, red, with sand and mica.....	12
Conglomerate, reddish, pebbles as much as 4 inches in diameter in matrix of clay, feldspar, and quartz.....	4
Clay, red, with sand and mica specks.....	15
Not exposed.....	175
Conglomerate, reddish gray, with well-rounded fragments of igneous and sedimentary rocks, including limestone.....	8
Conglomerate, white, well-rounded pebbles, maximum diameter 6 inches, of granite, obsidian, feldspar, and quartz.....	64

QUATERNARY DEPOSITS.

The Quaternary deposits consist of unconsolidated terrace gravels, such as are present in areas many feet above the valley levels both north and south of Alamosa Creek, and alluvium, such as is present along several of the larger stream valleys. Little attention was paid to deposits of this character, and the distribution as shown on the accompanying map probably does not include all the areas.

IGNEOUS ROCKS.

Younger than the Datil formation and younger even than at least some of the terrace gravels are the lava flows that cap several of the high mesas of the field. From the vesicular character of the material in certain parts of these lava caps it is assumed that the vents through which the lava was extruded are near at hand. Dikes and sills of basic material cut the Cretaceous rocks, as shown on the map (Pl. V).

STRUCTURE.

GENERAL FEATURES.

The field here described forms the southeastern part of San Juan Basin, a broad structural depression that occupies a very large area in northwestern New Mexico and southwestern Colorado. The Zuni Mountain uplift, which has a general northwesterly trend in McKinley and Valencia counties, to the north of this area, almost isolates the area of Cretaceous rocks south of the Atchison, Topeka & Santa Fe Railway, of which this field is a part, from the larger portion of the basin north of the railway.

The formations within the Alamosa Creek valley have a general dip toward the west, so that the oldest rocks are exposed at the eastern edge of the area. The attitude of the beds at numerous points within the area is indicated on the map by strike and dip symbols. Many faults and minor folds, most of which have a trend roughly parallel to the axis of the Zuni Mountains, interrupt the general structure of the area. Irregularly distributed over the field are dikes which have a trend practically parallel to the direction of the faults in the immediate vicinity and which fill fissures that apparently were formed by forces of the same character as those which gave rise to the faults. Because of the fact that in places cross faults cut and displace dikes, it is assumed that the forces which produced the faults were effective at a somewhat later period than those which caused the fissures that were filled with igneous rock to form dikes. Both dikes and faults cut the rocks of the Datil formation, but neither were found cutting the younger gravel deposits.

FOLDS.

Nearly all the anticlinal folds within this area are broken by faults, so that the faults become the most conspicuous part of the structure.

Red Lake anticline.—The Red Lake anticline is the largest fold in the area and extends northward from a point near old Burley post office, in sec. 21, T. 3 N., R. 8 W., to Broom Mountain, a distance of about 13 miles. The rocks along the west side of the fold dip at relatively low angles (3° – 8°) to the west; the beds on the east side of

the fault that marks the crest of the anticline dip as steeply as 48° E. but flatten appreciably within a mile or so. The fault, which is the most conspicuous feature of the structure, has a throw of several hundred feet, sufficient to bring beds of the upper half of the Miguel formation into contact with red clays and shales that are at least 200 feet below the Dakota sandstone. If petroleum exists in the rocks below the Dakota sandstone in this area, this fold provides what appears to be a fairly good place for its accumulation. It is probable that the beds are entirely sealed along the fault plane, and there is thus provided an effective barrier to migration of any oil and gas that may be present. Structure section *D-E* on the accompanying map (Pl. V) is drawn across the south end of the anticline.

La Cruz anticline.—The La Cruz anticline is a long irregular fold that extends into the field from the north, past the Tres Hermanos Buttes and La Cruz, into the northwest corner of T. 1 N., R. 5 W. This fold is cut by a large number of small faults, notably north of La Cruz and near the Chaves ranch, most of which strike parallel to the axis of the fold and none of which have a throw of much over 100 feet. Careful study of the structure will probably make it possible to separate this fold into several domes or small anticlines separated by low saddles; for example, the high part of the fold at the south end, where the Dakota sandstones and underlying "Red Beds" are exposed, is distinctly separated from the main portion of the anticline north of Alamosa Creek by the saddle near La Cruz, in sec. 13, T. 2 N., R. 6 W., where the Gallego sandstone (near the middle of the Miguel formation) is exposed on both sides of a narrow canyon. Dips of 2° to 18° prevail on the southwest side of this uplift and similar or steeper dips occur on the opposite side. Structure sections *A-B* and *D-E* on the map (Pl. V) illustrate the rock conditions across this anticline.

Cow Springs anticline.—A large number of small folds were noted within the area, one of the most promising of which appeared to be the one near Cow Springs, in the southwestern part of T. 4 N., R. 9 W., where the Bell Mountain sandstone and underlying shale of the upper part of the Miguel formation are exposed in two small areas. This fold appears to be free from faults and should provide an excellent place for the accumulation of oil in the sandstones of the lower half of the Miguel formation. The Dakota sandstone should be less than 2,000 feet below the surface in secs. 19 and 30, T. 4 N., R. 9 W.

PASTURE CANYON FAULT.

To the south, along the west side of the Pasture Canyon fault, the Bell Mountain sandstone is again exposed along Pasture Canyon and Pine Spring Canyon, while on the east side of the same fault younger beds form the surface, so that if the beds are sealed along the fault

GEOLOGY OF ALAMOSA CREEK VALLEY, N. MEX.

ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY

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plane, the area immediately west of the fault presents structural conditions favorable for the accumulation of oil. Sandstones in the lower half of the Miguel formation should be reached here by the drill at depths of less than 2,000 feet. (See section *C-D*, Pl. V.)

OIL AND GAS POSSIBILITIES.

The accumulation of oil and gas in commercial quantities in any area is dependent on two very important factors—the presence of oil or gas in the rocks and conditions favorable for their accumulation. In untested regions like that described in this report it may be possible to say positively that oil or gas is or is not present in the sediments below the surface, but a careful study of the available information regarding the character of those rocks at their outcrop, the degree to which they have been affected by metamorphism, and their structural attitude should afford grounds for certain conclusions as to the possibilities of the area.

Two theories have been advanced to explain the origin of petroleum, but the one that is most commonly accepted is that petroleum is a product of the alteration of certain organic materials which were laid down at the same time as the clay and sand which have since been consolidated into the shale and sandstone of the rock formations. Evidence has been presented to show that organic materials of certain types upon alteration become coal and carbonaceous shale, whereas materials of other types are transformed into oil shale and petroleum. White¹ points out that the quantity and quality of the petroleum are determined (1) by the composition of the organic deposit at the beginning of its dynamo-chemical alteration, and (2) by the stage of progress of the dynamo-chemical alteration of the organic substances—that is, in effect, by the extent to which the initial products have been either fractioned underground or filtered incident to migration. He also points out that the progressive devolatilization (carbonization) of the carbonaceous (coal) beds of the region corresponds to the progressive regional metamorphism, so that in areas where the regional metamorphism has progressed the farthest the coal shows the highest percentage of fixed carbon and the lowest percentage of volatile matter. White shows that if the percentage of fixed carbon in a normal coal or in the organic débris of a richly carbonaceous shale exceeds 65 per cent (pure coal basis) the possibilities that the coal-bearing formation or the rocks that underlie it may contain petroleum will be exceedingly small. He calls attention to the fact that wherever the regional alteration of the carbonaceous residues has passed the point marked by 70 per cent of fixed carbon in the pure coal, only gases and solid residues remain, and

¹ White, David, Some relations in origin between coal and petroleum: Washington Acad. Sci. Jour., vol. 5, pp. 189-212, 1915.

no commercial deposits of petroleum may be found. In fact, the commercial oil line seems to fall somewhat below the 65 per cent carbon point, though the exact percentage has not yet been fully determined. According to these conclusions oil deposits of commercial value will not be present, though gases may persist, in areas where the coals in or above the formations where the oil is hoped for are carbonized beyond the point indicated by 65 per cent of fixed carbon in the pure coal, and it is doubtful if commercial amounts of petroleum occur where the carbonization is as high as that.

Within the Alamosa Creek valley so far as known there are no oil seeps, asphalt deposits, or gas occurrences, but the shales of the lower part of the Miguel formation are of dark color and contain remains of organic material, both animal and vegetable, so that it is not inconceivable that there may be liquid petroleum and natural gas in the rocks. Coal occurs in both the Chamiso and the Miguel formations, and although it has not been mined and therefore unweathered material can not be obtained for fully trustworthy chemical analysis, the proximate analyses of two samples obtained from shallow prospects are available¹ and give a general idea as to the character of the coal and the stage of its devolatilization. Coal from a bed near the base of the Chamiso formation, in sec. 20, T. 3 N., R. 9 W., contains 55 per cent of fixed carbon (pure coal basis), and the coal near the middle of the Miguel formation, in sec. 8, T. 2 N., R. 6 W., shows 53 per cent on the same basis. Therefore oil may be present in these rocks. In fact, it seems probable that if petroleum is found in this area it will be of high grade and that it will be accompanied by natural gas.

Reservoir sands of excellent quality and rather exceptional continuity are present in the Miguel formation. The Bell Mountain sandstone at the top, the Gallego sandstone near the middle, and at least two unnamed but persistent sandstones in the lower part of the formation furnish beds almost unrivaled as sands in which oil may accumulate. These sands can be tested at points where the geologic structure is favorable for the accumulation of oil by drilling comparatively shallow holes, less than 2,000 feet in depth, in Cow Spring Canyon, near the center of sec. 30 or near the south line of sec. 19, T. 4 N., R. 9 W. Unfortunately these localities are so situated topographically that some road building will be necessary in order to get rig and materials to them, but it is probable that the necessary water can be obtained in the vicinity and fuel for the boilers can be mined within sight of the rig. Careful search will

¹ Campbell, M. R., Analyses of coal samples from various fields in the United States: U. S. Geol. Survey Bull. 541, p. 499, 1914. Campbell, M. R., and Clark, F. R., Analyses of coal samples from various parts of the United States: U. S. Geol. Survey Bull. 621, p. 332, 1916.

perhaps disclose other localities where the structure is equally favorable and where transportation conditions are more advantageous.

The formations older than the Cretaceous contain sands that may be worthy of testing, but in the work upon which this report is based little attention was paid to these lower formations. The Carboniferous includes some sand, as does also the overlying Triassic. The general character of at least one of these older sandstones is shown on Plate II. The cross-bedded character of this particular sand seems to be against it as an oil reservoir, but other sands may be much more favorable. A well 3,000 feet deep drilled near Red Lake, in sec. 2, T. 3 N., R. 8 W., should furnish satisfactory proof as to the oil possibilities of the formation below the Dakota. This locality, being on the west side of the fault and near the crest of the great anticline, is most favorable for a test of the lower rocks.



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THE UPTON-THORNTON OIL FIELD WYOMING

BY

E. T. HANCOCK

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THE UPTON-THORNTON OIL FIELD, WYOMING.

By E. T. HANCOCK.

INTRODUCTION.

LOCATION OF THE FIELD.

The territory here designated the Upton-Thornton oil field (see Pl. VI) includes two small dome-shaped folds and a small tract that yields a moderate quantity of oil of excellent quality and is entirely separate from either of these domes. One of these domes will be referred to as the Upton dome and the other as the Thornton dome. The productive territory lies in Weston and Crook counties, Wyo., near the Chicago, Burlington & Quincy Railroad, about 3 miles northwest of Thornton. It is about 20 miles southeast of the Moorcroft oil field, 90 miles northeast of the Salt Creek field, and 80 miles almost due north of the very promising Lance Creek field. Most of the producing wells are in sec. 33, T. 49 N., R. 66 W., and sec. 4, T. 48 N., R. 66 W. The Upton dome is about half a mile southwest of the town of Upton, in secs. 34 and 35, T. 48 N., R. 65 W., and secs. 2 and 3, T. 47 N., R. 65 W. The Thornton dome, which lies about 2½ miles southeast of Thornton, is included mainly in secs. 7, 8, 17, and 18, T. 48 N., R. 65 W.

ACKNOWLEDGMENTS.

The writer was assisted in the field work by Mr. Robert M. Campbell, for whose aid he desires to express his appreciation. He is also indebted for hearty cooperation to many of the citizens of Upton, especially to Messrs. R. C. Chappell and F. W. Palis, of the Southwest Oil Co., for valuable well data and for courtesies shown in many ways.

PURPOSE OF THE INVESTIGATION.

The purpose of the present investigation was to assist in the development of the field by making a detailed study of the stratigraphy in order to determine the stratigraphic position of the oil-bearing sands and the possibility of obtaining oil and gas in other sands, also to discover and locate such structural features as have elsewhere been found to have a definite relation to accumulations of oil and gas.

METHOD OF FIELD WORK.

The investigation that furnished a basis for the present report was made in July and August, 1918. The field observations were made and the maps prepared under the immediate supervision of the writer. In the process of mapping nearly all locations were made by triangulation, and elevations were determined by means of vertical angles. A line 10,400 feet long was measured on the railroad track southeastward from the station at Thornton, and with this as a base, a system of triangulation was extended over the area. Beginning with the known elevation of the railroad track at Thornton the elevation of each of the stations was determined by vertical angle.

HISTORY OF DEVELOPMENT.

An attempt was made to test the Thornton dome several years ago. Two holes were drilled near the top of the dome, and from the appearance of the cuttings near the holes the drill must have penetrated the red beds. The first apparent discovery of oil was made by the Southwest Oil Co. in its No. 2 well about three years ago. Since that time the company has drilled 12 more wells and has obtained oil in every one of them.

TOPOGRAPHY.

This field has no very conspicuous surface features. It lies along the southwest flank of the Black Hills uplift, and its topography is mainly the result of the action of wind, rain, and running water on the long, narrow outcrops of beds that present different degrees of resistance. For example, the Greenhorn limestone, which occurs between the great body of soft shale in the upper part of the Graneros formation and that of the Carlile shale, forms a continuous ridge from one end of the field to the other. Near Upton and about $2\frac{1}{2}$ miles southeast of Thornton local uplifting of the strata has given rise to relatively high areas exhibiting a reversal of dip along the east side. The doming of the strata near Upton has produced an elliptical hill nearly 100 feet higher than the surrounding area. That about $2\frac{1}{2}$ miles southeast of Thornton has given rise to a similar hill whose top is approximately 170 feet above the surrounding flat.

The drainage channels in this field occur, for the most part, in the valleys between the outcrops of the more resistant beds. The un-

METHOD OF FIELD WORK.

The drainage channels in this field occur, for the most part, in the valleys between the outcrops of the more resistant beds. The uplifting of the strata in the formation of the Thornton dome has given rise to a somewhat elevated tract from which the streams flow in opposite direction. A portion of the sediment that is picked up by running water near the top of this divide is carried southeastward and another portion goes northwestward. These two portions together completely encircle the Black Hills, one on the south and the other on the north. After being transported several hundred miles the sediment is again mingled in eastern Meade County, S. Dak., where Belle Fourche River joins the South Fork of the Cheyenne to form Cheyenne River.

GEOLOGY.

STRATIGRAPHY.

GENERAL SECTION.

No sedimentary beds crop out in this field which are lower in the stratigraphic column than those about 100 feet above the Dakota sandstone, the oldest formation of the Upper Cretaceous series in this region, but in attempting to determine the possibilities of the accumulation of oil and gas it is necessary to consider all the beds that lie within reach of the drill. In this field the principal known concentration of oil is in beds that reach the surface a short distance from the center of accumulation, but in most other fields the greatest accumulations are in porous sands which are sealed by the overlying impervious beds, especially where the entire series has been arched upward. Inasmuch as the beds in this field have been arched in two different localities outside of the productive area it is necessary to consider the relations, composition, and depth of some of the underlying beds. The following table shows the rock formations which crop out in this field, as well as those which were penetrated in the bore hole at the Antelope mine at Cambria, Wyo., and in the deep well at Cambria. The same formations from the Morrison down are represented graphically in figure 1.

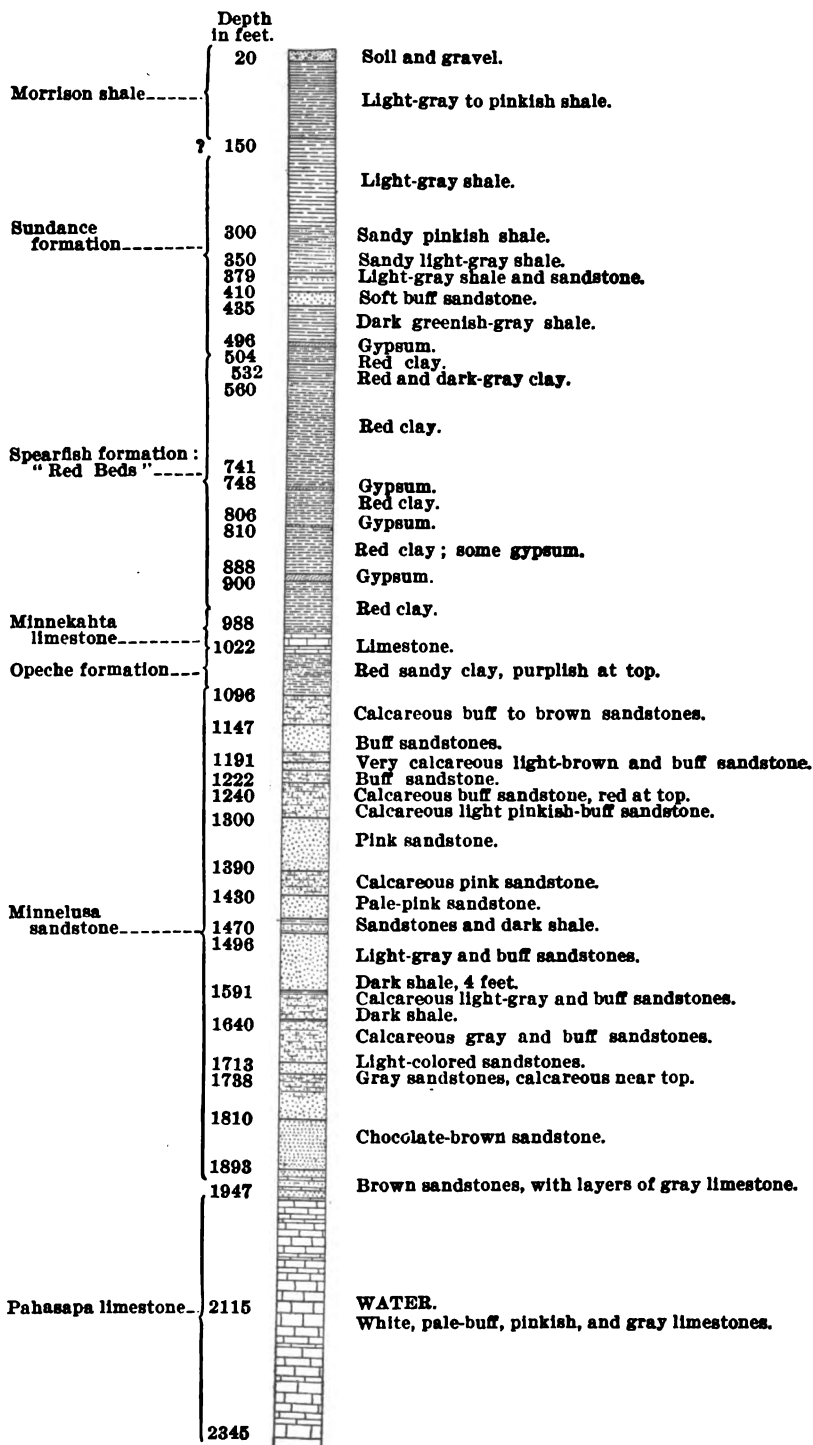


FIGURE 1.—Log of well at Cambria, Wyo. From Darton, N. H., U. S. Geol. Survey Geol. Atlas, Newcastle folio (No. 107), p. 8, 1904.

THE MULE CREEK OIL FIELD, WYOMING.

By E. T. HANCOCK.

INTRODUCTION.

LOCATION AND EXTENT OF THE FIELD.

The Mule Creek oil field, as shown in Plate VII, is in the northeastern part of Niobrara County, Wyo., about 4 miles from the east line of the State. It lies about 100 miles almost due east of the Salt Creek oil field and about 35 miles northeast of the Lance Creek field. The field, as mapped and described in this report, includes about 30 square miles of territory immediately south of Cheyenne River, in Tps. 39 and 40 N., Rs. 60 and 61 W. In this field there are two rather well defined anticlines, which for convenience of description will be referred to as the eastern and the western anticline. The top of the eastern anticline is about 18 miles almost due west of Edgemont, S. Dak., a flourishing town on the Chicago, Burlington & Quincy Railroad, from which most of the supplies going to the field are hauled. At a station called Argentine, some distance northwest of Edgemont, the railroad lies within 12 miles of the field.

ACKNOWLEDGMENTS.

In presenting this report the writer desires to express his thanks to David White for valuable suggestions and criticisms and to Carroll E. Dobbin for assistance in the detailed mapping. He also wishes to call attention to the public service rendered by the oil and gas operators, who very willingly furnished the records of deep borings.

PURPOSE OF THE INVESTIGATION.

A geologic investigation of this character requires, first of all, a thorough study of the outcropping strata. Such a study is made for two reasons. In the first place, a geologic report, to be of the greatest practical value, should describe each conspicuous bed or set of beds so vividly, with respect to composition, general appearance, effect upon topography, and other salient features that the oil oper-

ator, land owner, or prospective investor will be able to recognize it in the field. In the second place, it is very important to make a thorough study of the strata so as to be able to determine the structure accurately. In working out the structure it is necessary to ascertain the elevation and dip of many of the beds that come to the surface, but there is nothing to be gained by making careful instrumental determinations unless the investigator is reasonably certain regarding the relation, in the stratigraphic column, of the beds that crop out in different parts of the field. After the outcrops of the different beds have been traced and located on the map, both as to horizontal position and as to elevation, and after such well logs as are available are examined, it is possible to show by means of structure contours the attitude of any particular bed such as an oil sand throughout the field. The oil sand whose attitude is shown by contours on the map in this report is that in the Ohio Oil Co.'s producing well in the NE. $\frac{1}{4}$ sec. 24, T. 39 N., R. 61 W. At this point the record of the well shows the elevation of the sand, and nearly everywhere else the elevation has been calculated by means of other criteria.

FIELD WORK.

The field investigation that furnished the basis for the present report was made between July 8 and 17, 1919. The observations were made and the maps prepared under the immediate supervision of the writer, who was ably assisted in the field by C. E. Dobbin.

In the process of mapping nearly all locations were made by the triangulation method and elevations determined by means of vertical angles. A base line (A-B, Pl. VII) 7,900 feet in length was carefully measured along the high land from the south end of the western anticline to the SE. $\frac{1}{4}$ sec. 24, T. 39 N., R. 61 W., and the extremities were designated by means of a white flag. After the plane table had been oriented at the points designated, certain monuments and a number of the drilling rigs were located by intersection, and a system of triangulated points was extended throughout the field. In the absence of a permanent bench mark an elevation of 1,000 feet was assumed for the flag at the northwest end of the base line, and all other elevations were based upon the assumed elevation. Later on the elevation of the sandstone in the NE. $\frac{1}{4}$ sec. 5, T. 39 N., R. 60 W., was determined by reading a vertical angle on the Chicago, Burlington & Quincy Railroad track at Argentine, S. Dak., and the assumed elevations were revised in accordance with the new elevation thus determined. It is apparent, therefore, that the elevations shown on the accompanying map (Pl. VII) are only approximately correct.

In view of the purpose of the investigation, it was necessary to trace out and map the boundaries between the different formations and to determine the elevation and record the strikes and dips of the beds at many points. Where it was possible to trace a definite horizon within a formation and especially where the beds are inclined at a very low angle the structure was determined by means of elevations taken at short intervals.

LAND SURVEYS.

Only a small proportion of the section and quarter-section corners in this field are marked by pits and set stones. The locations of most of the corners have been established by local surveys and are at present indicated by means of plainly marked square posts.

SURFACE FEATURES.

The Mule Creek oil field forms a part of a relatively high area bordered on the north and east by the broad alluvial valley of Cheyenne River. The elevations in this field range from about 3,550 to 4,100 feet. The highest land is at the top of the eastern anticline, and the lowest is in the broad valley along the Cheyenne River. The eastern and western anticlines are rather well defined, but they differ considerably in relation between structure and surface form. A long period has elapsed since the sandstone which now forms the top of the eastern anticline was removed from the crest of the western anticline. Since the agencies of erosion swept this sandstone and the underlying Greenhorn limestone from the crest of the western anticline they have been actively at work removing the great body of soft shale between the limestone and the Dakota sandstone, and at the present stage of erosion the western anticline is marked by a drainage basin, whereas the eastern anticline is represented by a relatively high dome-shaped hill. The drainage basin of the western anticline is bordered on the south and west by a continuous ridge formed mainly by the Greenhorn limestone. The surface of the field is rather rough, owing to the presence of numerous small gullies, most of which unite to form larger ones extending northward and eventually reaching Cheyenne River. Most of the field is covered with grass and sagebrush. There are numerous cottonwood trees along the valley of the Cheyenne and an occasional cottonwood along the principal gullies, but the remainder of the field is entirely barren of timber. The field is readily accessible either by way of an excellent graded road leading west from Edgemont, S. Dak., or by way of the main road leading northwest from Edgemont along the west side of the valley of Cheyenne River. Most of the traffic seems to be over the road leading west from Edgemont, which enters the field at the south end, follows closely the axis of the eastern anticline, and leads down the slope to the area of Mowry shale at the top of the western anticline.

GEOLOGY.

STRATIGRAPHY.

GENERAL SECTION.

The highest beds in the sedimentary series mapped and described in this report are those which occur at the top of the Niobrara formation. The lowermost beds exposed are those which occur in the Mowry shale, but in a comprehensive discussion of the possibilities of oil and gas concentration it is necessary to consider such of the deeper beds as are within reach of the drill.

In the recently published report on the Upton-Thornton oil field,¹ which lies about 60 miles to the northwest and bears a similar relation to the Black Hills uplift, the writer has discussed, in addition to the formations that crop out, those which were penetrated in the bore hole at the Antelope mine at Cambria, Wyo., and also those in the deep well borings at Cambria. Inasmuch as the lowermost beds exposed in the Mule Creek field occur at practically the same horizon as the lowermost beds exposed in the Upton-Thornton field, the table of formations given in that report is repeated here, with certain alterations in the thicknesses of some of the units above the Dakota sandstone to conform to the writer's interpretation of the identity of some of the sands shown in the well log given on page 52.

FORMATIONS THAT DO NOT CROP OUT BUT ARE WITHIN REACH OF THE DRILL.

The lowest beds exposed in this field occur about 75 feet below the top of the Mowry shale. At some localities not far distant, however, the underlying beds are well exposed. These beds are exhibited where they are upturned along the southwest flank of the Black Hills uplift to the north and east, and also in the vicinity of Wright's camp, near the north end of the Old Woman anticline, a few miles to the southwest. Northeast of this field, in the vicinity of Newcastle, there is immediately above the Dakota sandstone about 225 feet of dark shale that erodes very readily, producing a relatively low area between the long dip slopes formed by the Dakota sandstone and the more or less jagged ridge formed by a sandstone lentil that overlies this shale. The extent of development of this sandstone lentil along the flanks of the Black Hills uplift and in the adjacent area is a matter of vital interest to oil and gas operators, not only because oil issues from it in considerable quantities at Newcastle, but also because it is one of the main oil-producing sands at other localities in Wyoming. In the Upton-Thornton oil field it is a reddish-brown, moderately soft sandstone encircling the central portion of the Thornton dome and occurring as isolated patches near the top

¹ Hancock, E. T., The Upton-Thornton oil field, Wyo.: U. S. Geol. Survey Bull. 716, pp. 17-34, 1920 (Bull. 716-B).

Rock formations in the Mule Creek field, Wyo.

[From outcropping beds and deep borings at Cambria, Wyo.]

System.	Series.	Group, formation, and member.		Character.	Thick- ness (feet).
Cretaceous.	Upper Creta- ceous.	Colorado group.	Niobrara formation.	Soft shaly limestone or impure chalk, including some clay and sand.	200
			Carlisle shale.	Dark shale with thin beds of soft sandstone (Wall Creek sandstone member) near the base.	700
			Greenhorn limestone.	Impure slabby limestone.	50
			Graneros shale.	Dark-gray to black shale, including many large calcareous concretions, especially in the upper part.	575
				Mowry shale member.	100
				Dark sandy shale grading upward into typical Mowry shale.	25
				Newcastle sandstone member.	3 to 15
				Dark-gray to black shale.	175
		Dakota sandstone.		Thin-bedded to massive hard buff sandstone.	60
	Lower Creta- ceous.	Fuson formation.		Shale and thin-bedded sandstone.	20
		Lakota sandstone.		Sandstone, in part conglomeratic, with some coal beds near the base.	199
Cretaceous (?)	(?)	Morrison formation.		Light-gray to pinkish shale.	130
Jurassic.	Upper Jurassic.	Sundance formation.		Light-gray to dark greenish-gray and pinkish sandy shale, with a 25-foot sandstone near the base.	346
Triassic (?)		Spearfish formation.		Gypsum and red clay beds in alternating succession ("Red Beds").	492
Carboniferous.	Permian (?).	Minnekahta limestone.		Light-gray to pinkish or purplish limestone.	34
	Pennsylvanian.	Opeche formation.		Red sandy clay, purplish at the top.	74
		Minnelusa sandstone.		Light-gray to buff calcareous sandstone.	851
	Mississippian.	Pahasapa limestone.		White, pale-buff, pinkish, and gray limestone.	398

of the dome. It is apparently only 2 or 3 feet thick at the northwest end of the dome, but on the south end it includes about 15 feet of reddish to light-yellow sandstone associated with some carbonaceous shale. In the vicinity of Newcastle, where considerable oil seeps from this sand, it is about 35 feet thick and forms a ridge about 500 feet above the railroad. It continues as a very conspicuous ridge as far southeast as the L. A. K. ranch, on Stockade Beaver Creek, but from that point southward it becomes thinner, appearing only at intervals as lenses in the shale. It seems to be rather well developed, however, near the north end of the Old Woman anticline, about 12 miles southwest of the Mule Creek field. The conditions there are as follows: About three-quarters of a mile northwest of Wright's camp the Dakota sandstone forms a long dip slope. The sandstone is overlain by about 200 feet of dark shale. The shale is overlain by a succession of sandstones and carbonaceous shale beds which give rise to a very conspicuous ridge. This group of beds, the details of which are shown in the following section, is in part at least equivalent to the oil-bearing sand at Newcastle.

Section of sandstone and carbonaceous shale beds northwest of Wright's camp.

	Ft.	in.
Sandstone, very hard, forming east dip slope.....	2	6
Mainly black carbonaceous shale.....	9	0
Sandstone, yellowish brown, massive.....	6	6
Shale, sandy, carbonaceous.....	9	
Sandstone, rather thinly bedded.....	7	0
Shale, black, carbonaceous.....	5	6
Sandstone, yellowish brown, hard and massive.....	4	6
Shale, sandy.....	1+	
	36+	

The group of sandy beds described above is doubtless widely distributed throughout Wyoming. It was recognized by the writer on the south slope of the Como Ridge, about 6 miles east of Medicine Bow, and is in all probability equivalent to the sand that occurs near the middle of the Thermopolis shale at different localities in the Big Horn Basin and is commonly known by drillers as the Muddy sand. These beds attain an unusual thickness at Newcastle and are oil bearing at that locality, so for convenience of description they are named the Newcastle sandstone member.

The beds immediately above the Newcastle sandstone are plainly exhibited along the north side of the Thornton dome, described in the report on the Upton-Thornton oil field. Encircling the sandstone in the Thornton dome is an area which is underlain by dark shale. The shale that overlies the Newcastle sandstone and gradually merges upward into the typical Mowry shale is about 50 feet thick. The upper half of the Mowry shale is exposed in the Mule

Creek field at the top of the western anticline, and for that reason the entire formation is described on succeeding pages along with the others which crop out in this field.

The section from the top of the Dakota sandstone down into the Morrison is well shown in the bore hole of the Antelope mine at Cambria, Wyo. At that locality, which is about 40 miles north of the Mule Creek field, the following section is exhibited:

Section in bore hole of Antelope mine at Cambria, Wyo.²

Dakota:	Feet.
Sandstone, thin bedded.....	20
Sandstone, hard, massive, buff.....	40
Fuson: Shale and talus.....	20
Lakota:	
Sandstone, light colored, conglomeratic in part.....	60
Talus and sandstone ledges.....	70
Sandstone, light gray, soft, fine grained.....	50
Coal.....	7
Sandstone, hard, light brown.....	5
Sandstone, soft, dark brown.....	2
Sandstone, light gray, moderately hard.....	1½
Coal with sandstone, shale, and pebbly layers.....	½
Sandstone, dark gray, soft.....	1
Coal, shales, and sandstone.....	2
Morrison:	
Fire clay, gray.....	3
Sandstone, light gray, moderately hard.....	1½
Fire clay.....	7½
Sandstone, gray, upper half very hard.....	4
Shales with some thin sandstones.....	54+

The deep-well boring at Cambria probably furnishes as detailed and reliable information regarding the underlying formations as can be obtained. This well was begun just below the 7½-foot bed of fire clay in the above section and was continued to a depth of 2,345 feet. The log of the well, as shown in figure 1, was compiled by N. H. Darton from samples sent to Washington and from a set of borings admirably preserved in glass tubes by Mr. Mouck, the superintendent of the Cambria mines. According to this log and the section from the bore hole of the Antelope mine there are 2,636 feet of beds between the top of the Dakota sandstone and the bottom of the deep well. In all probability there is a slight variation in the total thickness of the formations between Cambria and the Mule Creek field, but on the assumption that the total thicknesses are the same, the beds which occur at the bottom of the deep well at Cambria are about 2,900 feet below the surface at the top of the western anticline at Mule Creek and 3,770 feet below the surface at the top of the eastern anticlines.

² Darton, N. H., U. S. Geol. Survey Geol. Atlas, Newcastle folio (No. 107), p. 4, 1904.

A careful analysis of the logs of the bore hole and the deep well at Cambria shows that the principal sandstones beneath the surface in this region are included in the Dakota, Lakota, and Minnelusa formations. At the Antelope mine the Dakota is composed of an upper thin-bedded sandstone and a lower hard, massive buff sandstone. The Lakota formation is composed mainly of sandstone, in part conglomeratic, with coal beds near the base. The Morrison is composed mainly of light-gray to pinkish shale, with beds of sandstone and fire clay near the top. The Sundance formation is composed of light-gray to dark greenish-gray and pinkish sandy shales, including near its base one soft buff sandstone about 25 feet thick. Extending from the base of the Sundance down to the Minnekahta limestone is the Spearfish formation, commonly known as the Triassic "Red Beds," including alternating beds of gypsum and red clay. The Permian series is probably represented by the Minnekahta limestone, about 34 feet thick, and the underlying Opeche formation, composed of 74 feet of red sandy clay, somewhat purplish at the top. The Carboniferous from the base of the Permian series to the bottom of the deep well is composed essentially of sandstones and limestones. The Minnelusa formation, of Pennsylvanian age, consists almost entirely of light-gray to buff calcareous sandstones, the total thickness of which is 851 feet. From the base of this formation to the bottom of the well there is 398 feet of massive limestone.

FORMATIONS EXPOSED.

UPPER CRETACEOUS SERIES.

COLORADO GROUP.

The Colorado group in this locality includes the Niobrara formation, Carlile shale, Greenhorn limestone, and Graneros shale. The last three formations are equivalent to the Benton shale of other areas.

Graneros shale.—Overlying the Dakota sandstone in this region is a mass of soft, fine-grained deposits whose total thickness is about 885 feet. According to Gilbert² the name Graneros was first suggested by R. C. Hills for an equivalent group of beds exposed along Graneros Creek about 20 miles south of Pueblo, Colo. The greater part of the mass consists of dark-gray to black shale, which is very soft and which yields readily to the ordinary agencies of erosion. About 175 feet above the base of the formation there is commonly what may be called a sandy zone. This zone of sandy material—here named the Newcastle sandstone member, from Newcastle, Wyo., where it is conspicuously developed—varies in thickness and also in composition in different localities, as explained on pages 38–40, but it can generally be recognized by anyone reasonably familiar with their stratigraphy. It is commonly overlain by 25 to 50 feet of dark shale, which merges upward into the typical Mowry shale.

² Gilbert, G. K., The underground water of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, p. 570, 1896.

The term "Mowrie beds" was first applied by Darton⁴ in his description of the Big Horn region to a group of beds exposed along Mowry⁵ Creek, northwest of Buffalo, Wyo. The Mowry shale in more or less typical form is exposed in this field at the top of the western anticline, where, as near as the writer could estimate, erosion has removed about one-half of the original thickness. Where the Mowry is upturned along the southwest flank of the Black Hills uplift it ordinarily includes about 150 feet of hard light-gray sandy shales, many of the individual plates of which exhibit fish scales. These shales, on weathering, become almost white, in strong contrast with the softer dark-colored shales above and below, and, owing to their superior hardness, they do not erode as rapidly as the overlying and underlying shales, so that the position of the Mowry shale member is commonly indicated by a more or less continuous ridge or by a succession of low hills covered by a moderately dense growth of evergreens. In this field some of the shale has been removed from the top of the western anticline, and certain thin layers of sandstone are laid bare for several hundred feet. The top of the Mowry shale is well exposed along the west side of the anticlines near the center of sec. 2, where it is marked by two 4-foot beds of bentonite separated by 8 feet of dark shale. This bentonite is a light-gray to yellowish fine-textured soft and massive clay. It is a hydrous silicate of alumina with certain other constituents in small proportions and is characterized by its highly absorbent qualities. The upper bed of bentonite is overlain by about 10 feet of dark-gray flaky shale, and this in turn by very black shale containing considerable heavy black, iron-stained material in thin layers and also in individual concretions. The bentonite and the associated beds are valuable horizon markers in eastern Wyoming because of their persistence over wide areas.

From the Mowry shale member up to the Greenhorn limestone the Graneros formation is composed essentially of dark shale containing scattered calcareous concretions.

Greenhorn limestone.—Immediately overlying the upper dark shale of the Graneros formation is a thin but very persistent series of beds of impure limestone known as the Greenhorn limestone. According to Gilbert,⁶ this limestone first took its name from Greenhorn Creek and Greenhorn station, about 14 miles south of Pueblo, Colo. The entire limy series does not generally exceed 50 feet in thickness, but these limestone beds are so much harder than the beds above and below that they give rise to a more or less continuous ridge bordering the western anticline on the west and south and to a considerable extent on the east. They also give rise to a very prominent escarp-

⁴ Darton, N. H., Comparison of stratigraphy of Black Hills, Bighorn Mountains, and Rocky Mountain Front Range: Geol. Soc. America Bull., vol. 15, p. 400, 1904.

⁵ Formerly sometimes spelled "Mowrie."

⁶ Gilbert, G. K., op. cit., p. 570.

ment extending from east to west along the north side of Cheyenne River. Where the resistant beds of impure limestone have not given rise to a well-defined ridge their outcrop is indicated on the surface by a narrow belt having a distinctly lighter color and curving in obedience to the gradual change in the strike of the beds. On weathering the thin layers of impure limestone become very hard and resistant, and where the beds dip steeply the outcrop is commonly marked by a series of thin slabs projecting above the surface. Many of these slabs contain numerous impressions of *Inoceramus labiatus*, a fossil that rarely occurs in other formations of Benton age.

Carlile shale.—The name Carlile shale was first applied by Gilbert¹ to a body of shale resting upon the Greenhorn limestone in the vicinity of Carlile Spring and Carlile station, about 21 miles south of Pueblo, Colo. In the more recent reports of the Geological Survey the same name is applied to a group of beds having the same stratigraphic position but differing considerably from those at the type locality. In the report on the Upton-Thornton oil field the writer calls attention to the fact that the lower 230 feet of the Carlile shale is composed essentially of soft sand and very sandy shale. These beds are all exposed in the railroad cut about 2 miles northwest of Thornton, Wyo. The lowermost 200 feet of the Carlile shale is not well exposed in the Mule Creek field, and hence that part of the formation is believed to be composed essentially of shale and imperfectly consolidated sandy beds. The upper portion of the section exhibited in the railroad cut near Thornton is represented in this field by a group of sandstones and carbonaceous shale beds about 35 feet thick. The beds of this series crop out in the western anticline a few hundred feet outside of the Greenhorn limestone and also along the gulches both east and west of the eastern anticlinal axis, and they occur at the surface at the producing well on the highest part of the eastern anticline. From the stratigraphic position of these sandstones and associated beds they are believed to represent the Wall Creek sandstone of areas farther west. The beds are well exposed in the NE. $\frac{1}{4}$ sec. 7, T. 39 N., R. 60 W., where the following section was measured:

Section showing the beds which constitute the Wall Creek sandstone member in the NE. $\frac{1}{4}$ sec. 7, T. 39 N., R. 60 W., Wyo.

	Feet.
Sandstones, yellowish brown, soft and very irregularly bedded.....	7
Shale, dark, sandy, and carbonaceous.....	4
Sandstone and dark carbonaceous shale, interbedded.....	5
Shale, dark, becoming very sandy near the top.....	9
Shale, dark gray and very sandy, including numerous thin beds of sandstone.....	10

¹ Gilbert, G. K., op. cit., p. 570.

The following species of invertebrate fossils were obtained from the above-described beds near the main road about a mile farther west, in the NE. $\frac{1}{4}$ sec. 12, T. 39 N., R. 61 W. They were examined by T. W. Stanton, who states that they belong to the Benton fauna and indicate a horizon within the Carlile shale.

Aporrhais sp.

Corbula sp.

Inoceramus fragilis Hall and Meek.

Lunatia sp.

Prionocyclus wyomingensis Meek.

Prionotropus sp. related to *P. hyatti* Stanton.

Scaphites warreni Meek and Hayden.

Throughout the eastern part of the Mule Creek field the sandy beds shown in the above section occur at or very near the surface, and either all or a large part of the upper portion of the formation is eroded, but in the western part of the field the upper portion is present. In that area the Carlile dips rather steeply beneath the Niobrara formation and, like that formation, presents very few exposures.

Niobrara formation.—The Niobrara formation rests unconformably upon the Carlile shale and is exposed throughout a narrow belt along the south and west sides of the field. This formation was first named in the reports of the Hayden Survey, and the type locality is along Missouri River near the mouth of the Niobrara, in northeastern Nebraska. At that locality the beds form vertical cliffs from 90 to 100 feet in height. In the Mule Creek field the characteristics of the formation are best exhibited east of the main road, at the south end of the field. It includes about 200 feet of soft shaly limestone or impure chalk containing more or less shale, fine sand, and clay. It also includes some thin beds of hard limestone which consists of aggregations of *Ostrea congesta*, a fossil very distinctive of the formation. The unweathered exposures of the formation are usually grayish, but the weathered outcrops are decidedly yellow. The formation is therefore very conspicuous, although the constituent beds are soft and give rise to few noticeable ridges.

STRUCTURE.

GENERAL FEATURES.

The Rocky Mountain Front Range and the Black Hills uplift are connected by what is commonly known as the Hartville uplift, an irregular arch whose axis is indicated by exposures of granite, schist, and limestone near Hartville and Lusk, at Rawhide Butte, and at a number of other localities. The position of the axis is also indicated by the Old Woman anticline, which brings to the surface the uppermost beds of the Sundance formation. The Mule Creek oil field lies in the direct continuation of this axis, about midway between the

Old Woman anticline and the rather steeply dipping beds along the southwest flank of the Black Hills. The great disturbance which brought the major uplifts into existence also resulted in the formation of two well-defined anticlines in the Mule Creek field, but the strata involved in these folds were uplifted relatively little in comparison with the arching of the same strata in the Old Woman anticline or the Black Hills uplift. The location and form of the two principal anticlines of the Mule Creek field are clearly shown on the accompanying geologic map (Pl. VII). The smaller one of the two lies south and east of the larger, and for want of better names they are called the eastern and western anticlines.

METHODS OF REPRESENTING STRUCTURE.

Different methods have been used from time to time by the Geological Survey for the purpose of conveying to the reader an adequate notion regarding the folding, or what is frequently referred to by drillers and others as the "lay" of the beds. The structure is ordinarily shown by means of either structure sections or structure contours. The structure section is based mainly upon the degree of inclination of the beds at the surface, upon measured stratigraphic thicknesses, and upon data from deep borings. It shows how a portion of the earth's crust would appear if it were cut by a vertical plane and the material on one side of the plane were removed. The structure section is an excellent aid in the explanation of structure where the beds dip steeply, but where they are inclined only a few feet to the mile it is difficult to bring out certain structural features without exaggerating the vertical scale more than is desirable. In oil and gas investigations, where the interpretation and representation of structure are extremely important, the method of representing structure by contours has been adopted because of its practical value and also because it is easily understood. The following explanation is offered for the benefit of those who are unfamiliar with the definition, degree of accuracy, and practical application of structure contours:

Structure contours are lines drawn on a map to show the elevation of some particular stratum above or below a certain datum plane, as, for example, mean sea level. They are designed to show the shape and magnitude of the folds and, in general, the irregular warping of the beds. In the preparation of the accompanying map (Pl. VII) it was decided to show, throughout the field, as accurately as the data available would allow, the elevation of the sand that yields oil in the Ohio Oil Co.'s producing well in the NE. $\frac{1}{4}$ sec. 24, T. 39 N., R. 61 W. Any particular contour is the line of intersection between that sand and a horizontal plane a certain distance (for example, 2,000 feet for the 2,000-foot contour) above sea level. Each struc-

ture contour represents a level 100 feet above or below that of the one adjacent, and hence it follows that where the contours are closely spaced the beds are steeply inclined, and where they are widely spaced the formation approaches much nearer to horizontality.

Structure contours furnish a convenient method for presenting to the reader a comprehensive idea regarding the structure of an entire field. Their practical value depends, of course, upon their accuracy, and their degree of accuracy depends upon the number of data available. In certain developed oil fields it is possible to obtain numerous well logs and recognize in them, either directly or from other beds, the position of the particular bed which it is desired to contour. After a structure-contour map is made for such a field the depth to the contoured bed at any point can be ascertained very accurately by subtracting from the surface elevation at that point the elevation of the contoured bed as shown by the structure contour. In other fields, where little drilling has been done and especially where many of the records were not preserved, it is necessary to depend almost entirely upon surface data, such as dips, measured intervals between beds, and elevations of traceable beds in making a structure-contour map. In such fields the structure contours are not likely to be drawn as accurately, but the demand for information is often so acute that it becomes necessary to sacrifice a certain degree of accuracy in order to insure more prompt publication. On the map of the Mule Creek field the structure contours are drawn mainly on the basis of dips, measured intervals, and elevations of traceable beds. At the Ohio Oil Co.'s producing well at the top of the eastern anticline, in the NE. $\frac{1}{4}$ sec. 24, T. 39 N., R. 61 W., the Wall Creek sandstone occurs at the surface and the oil sand occurs at a depth of 1,394 feet. Fortunately, it was possible to trace and determine the elevation of the Wall Creek sandstone throughout a large portion of the field and from it to determine the elevation of the oil sand. The top of the Greenhorn limestone is very close to 200 feet below the top of the Wall Creek sandstone, and therefore it is about 1,200 feet above the oil sand. It follows, then, that the top of the Mowry shale is about 570 feet stratigraphically above the oil sand if the thicknesses of the different formations and members are approximately those shown in the table of formations on page 39.

STRUCTURE OF THE MULE CREEK FIELD.

The structural relation of the Mule Creek field to the surrounding region is discussed on pages 45-46. As a result of the forces which were active in this region, two well-defined anticlines were developed in the Mule Creek field. The axes of these two anticlines trend nearly due north, and the more pronounced of the two is a little north and west of the other. The two anticlines are separated by a sharply

curving syncline. As shown on Plate VII, the axis of the western anticline extends from sec. 23, T. 39 N., R. 61 W., to the northeast corner of the same township and from that point in a sweeping curve to the northeast corner of sec. 30, T. 40 N., R. 60 W., and in all probability for some distance farther east. The beds involved in this anticline are at most points inclined from 5° to 15° , but along the west side opposite the small area of Mowry shale they dip as steeply as 26° . East of the axis the beds are inclined from 14° to 16° at the south end, but farther north they become flatter as the fold broadens out. The axis of the eastern anticline extends from the synclinal axis southward to the Ohio and Midwest wells, at the top of the ridge near the west line of sec. 19, T. 39 N., R. 60 W., and thence it follows the township line closely for an indefinite distance southward. From this axis the beds are inclined at angles ranging from 3° to 6° . The axis of the syncline extends from the NE. $\frac{1}{4}$ sec. 23 to the SE. $\frac{1}{4}$ sec. 12, T. 39 N., R. 61 W., where it makes a sharp curve, and from that point it extends toward the middle of the north side of sec. 20, T. 39 N., R. 60 W.

When the two anticlines came into existence the same beds were forced up much higher in the western than in the eastern anticline, as is shown by the following facts. The Wall Creek sandstone, which crops out at the top of the eastern anticline, is about 236 feet higher than the Mowry shale, exposed at the top of the western anticline, but according to the thicknesses as given in the table of formations on page 39, there are about 900 feet of beds between the Wall Creek sandstone and the uppermost exposed beds of the Mowry. If the tops of the two anticlines were at exactly the same elevation, it is evident that the difference in elevation of corresponding beds would be equal to the stratigraphic interval, or 900 feet, but inasmuch as the top of the western anticline is 236 feet lower than that of the eastern anticline, it follows that any particular bed in the western anticline is 900 minus 236, or 664 feet higher than the corresponding bed in the eastern anticline. The reader should keep in mind, however, that this calculation is based on the log of the Ohio Oil Co.'s discovery well and the assumption that some of the formations are considerably thinner in the Mule Creek field than they appear to be in the Upton-Thornton field.

OIL AND GAS.

FACTORS THAT GOVERN THE ACCUMULATION OF OIL AND GAS.

A careful comparison of the structure of the rocks and its relation to concentrations of oil and gas in many parts of the world has given rise to the structural or anticlinal theory. The conditions that control the accumulation of oil and gas, according to this theory, are briefly as follows:

(a) A reservoir rock, commonly known as the oil "sand," although it may be a very sandy shale, a fractured rock of some kind, a loose conglomerate sufficiently porous to allow the accumulation of oil or gas, or a porous limestone or dolomite composed largely of interlocking crystals of calcite or oolitic grains.

(b) An impervious cap rock to seal over the reservoir rock and prevent the upward escape of the oil and gas.

(c) Folds in the rock favoring the accumulation and confinement of oil and gas in certain localities, these substances migrating from more extensive areas of adjoining beds that are less favorably situated for their retention.

(d) Saturation of the rocks by ground water, on which the oil and gas will move on account of their lower specific gravity and be forced along the more porous strata into the upper parts of the folds.

According to the anticlinal theory, if a porous rock containing gas, oil, and water is folded between other rocks which are non-porous, these substances, under the influence of gravity, separate and arrange themselves according to density in the porous zone. The gas, being the lightest, rises to the crest of the anticline, the oil separates out below, and the water occupies the deeper portions of the beds. It is a well-recognized fact that oil and gas have entered porous sands from adjacent beds and that they have in many areas migrated long distances to the points of concentration, but it is not absolutely demonstrated just what forces are the most active in causing oil, gas, and water to migrate from the fine clays and shales into the porous sands. Neither has it been proved beyond controversy to what extent gravity and capillary attraction influence the movement of those substances along porous sands that are inclined at an extremely low angle.

Detailed field observations have shown not only that many of the concentrations of oil and gas are intimately related to anticlines and domes, but also that gas, oil, and water adjust themselves in the strata in the manner stated above. Although the recognition of these facts has caused most geologists to accept the anticlinal theory in its broader aspects, many geologists are willing to accept it only in a modified sense, as recent study has shown that accumulations of oil and gas occur not only in the crowns of the arches but also in many places on the flanks of the folds where the dips are less steep for some distance, the local flattening forming structural terraces. Recent studies indicate also that the conditions of accumulation are entirely different in saturated and unsaturated rocks—that in thoroughly saturated rocks the oil and gas are borne upward on the sheet of underground water and are caught in the crowns of the arches, whereas in dry rocks the principal point of accumula-

tion of oil may be near the bottoms of the synclines or at any place where the forces obstructing the movement of particles of oil are equal to or in excess of those which promote such movement.

In saturated rocks the ideal structural form is the dome which includes a thick bed of porous sand that is effectively sealed above and dips gently for considerable distances, but such a form is not common in nature. In many domes the dips are limited by other structural features, and in consequence the collecting area is small. The oil sands may be lenticular, or continuous sands may be offset along fault planes. If the fault remains partly open fluids migrating through the porous sands may rise to the surface and escape. It has been found that many oil seeps are characterized by deposits of asphalt. If the fault is sealed by clay, asphalt, or some other impervious substance the oil and gas may concentrate in the sand near the fault plane, and the result is practically the same as when the sand is lenticular. Thus an open fault fissure may prevent concentration at the top of an anticline or dome, and a fissure effectively sealed may produce local concentration at some point along the flank. The migration of oil, gas, and water through porous sands up along the flank of the most ideal structural feature may be retarded where the beds abruptly flatten or where the porosity of the sand decreases, and it may be entirely obstructed where a dike of igneous rock cuts across the sands. From the facts above outlined it is not surprising that some concentrations of oil and gas occur in places where, from all surface indications, the conditions are unfavorable, whereas some areas that appear to have the most favorable structure are barren. These conditions are mentioned briefly, not with the object of depreciating the value of the anticlinal theory as a working hypothesis, but merely to emphasize the necessity for making in every field a thorough study of all the conditions which may in any way retard the movement of fluids and result in concentration.

POSSIBLE PRODUCTIVE SANDS.

In an attempt to apply what has been said to the Mule Creek field certain facts become at once apparent. In the first place, a careful examination of the beds exposed along the southwest flank of the Black Hills shows that there are many porous beds in this field beneath the horizon of the Wall Creek sandstone and within reach of the drill. It is also apparent from the table of formations (p. 39) that many of these porous beds are overlain by impervious beds, and the geologic map (Pl. VII) shows plainly that the entire series has been arched upward, forming two well-defined anticlines. With these facts in mind we should attempt to ascertain, from experience in adjacent fields, which of these porous beds are the most likely to yield oil and gas.

In the description of the lowest beds exposed in the Mule Creek field (pp. 38-42) considerable emphasis is placed on the Newcastle sandstone, which at Newcastle occurs about 50 feet below the Mowry shale and about 225 feet above the top of the Dakota sandstone. These sandy beds are widely distributed throughout eastern Wyoming, and they exhibit considerable variation from one locality to another, even along the southwest flank of the Black Hills. They contain oil at Moorcroft and Newcastle and gas in the Big Horn Basin, and are probably the main oil and gas sands in the Lance Creek and Rock Creek fields. The Greybull sandstone member of the Cloverly formation produces most of the oil and gas of the Greybull field. In the Powder River field the approximate stratigraphic equivalent, which was designated the Dakota (?) sandstone, is the principal oil-bearing formation, but a small quantity of oil occurs in at least two sands in the Morrison, and it is also present in small quantity in the Sundance formation. The Carboniferous portion of the Embar group bears oil in the Lander field, and a 1,730-foot boring on the Old Woman anticline, about 15 miles southwest of the Mule Creek field, is reported to have found considerable oil, doubtless in the Minnelusa sandstone, also of Carboniferous age.

DEVELOPMENT IN THE MULE CREEK FIELD.

Attention was first directed to the Mule Creek field by the recognition of the western anticline, and the earliest development was in the nature of shallow drilling, mainly for the purpose of validating claims. As usual, the interested persons reported the "commercial discovery" of oil, but accurate records of the wells were apparently not preserved. The first important discovery of oil was made early in 1919 by the Ohio Oil Co. near the top of the eastern anticline, in the SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 24, T. 39 N., R. 61 W. When the writer's field examination was completed this was the only producing well in the field, but since that time a number of other wells have been brought in near the axis of the eastern anticline. The writer is in possession of very little information concerning the recently completed wells, and consequently the detailed descriptions are omitted. The location and character of the recent wells, as shown on the geologic map (Pl. VII), are based upon a map furnished by the Ohio Oil Co. According to a statement in the Oil and Gas News of November 6, 1919, the producing wells at that time averaged from 125 to 150 barrels a day and the total production of the field exceeded 1,000 barrels a day. Like most of the oil obtained from that horizon in Wyoming, the Mule Creek oil is of low specific gravity and has a paraffin base. It is reported that the Illinois Pipe Line Co. has begun laying a pipe line from the field northeastward to Dakoming, a station on the Chicago, Burlington & Quincy Railroad near the line between South Dakota and Wyoming.

In order that the reader may become familiar with the stratigraphic position of the sand from which the oil is obtained in the discovery well, the log of that well is given below.

Log of Ohio Oil Co.'s producing well in the SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 24, T. 39 N., R. 61 W., Wyo.

[Driller's interpretation.]

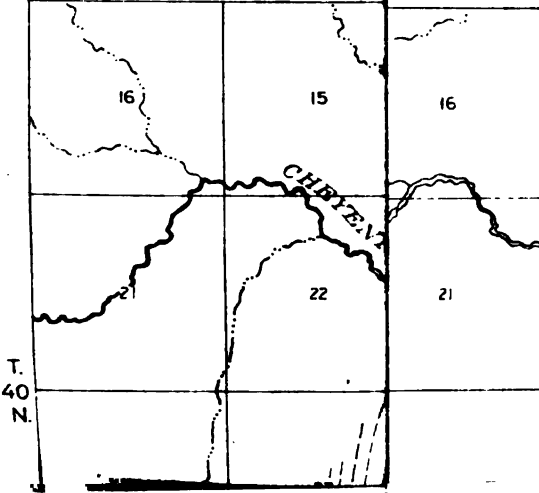
	Thickness.	Depth.
	<i>Feet.</i>	<i>Feet.</i>
Sandy shale.....	300	300
Shell.....	1	301
Blue hard shale.....	274	575
Shell.....	2	577
Blueshale.....	16	593
Shell.....	2	595
Blueshale.....	55	650
Shell.....	2	652
Blue and gray shale.....	93	745
Sand; showing of gas.....	5	750
Blueshale (Newcastle sandstone horizon 175 feet above base).....	385	1,135
Dry sand.....	25	1,160
Water sand.....	109	1,269
Blue-gray shale.....	22	1,291
Blueshale containing streaks of sand.....	23	1,314
Sand.....	57	1,371
Sandy shale resembling talc (oil sand).....	23	1,394

The above log indicates that the drill penetrated more than 200 feet of sand before reaching the principal oil-bearing stratum. According to the thickness of the different members as shown in the table of formations accompanying the recent report on the Upton-Thornton field, the top of the Newcastle sandstone would be near the base of the "water sand" in the above log, but where the Newcastle sandstone crops out along the southwest flank of the Black Hills and in the Old Woman anticline it rarely exceeds 50 feet in thickness. In the Lance Creek field it is composed of an upper and a lower sandstone separated by hard shale, and the combined thickness of the three beds is probably not greater than 50 feet. Owing to the fact that the Newcastle sandstone is scarcely recognized immediately east of this area, where the beds are upturned in the vicinity of Edgemont, it seems reasonable to suppose that this sandstone is very thin in the Mule Creek field, and furthermore, that the "dry sand" and "water sand" noted in the above well log together constitute the Dakota sandstone, that the underlying blue-gray shale is equivalent to the Fuson shale, and that the oil is derived from an oil sand in the Lakota sandstone. In arriving at this conclusion it is necessary to assume that the formations above the Dakota are somewhat thinner at Mule Creek than they appear to be in the Upton-Thornton field, but nevertheless the field evidence seems to justify such a conclusion.

Considerable drilling has been done on the western anticline, mainly for the purpose of validating claims. Some of these wells, in all probability, were drilled below the horizon of the Newcastle sand. More recently considerable drilling has been done near the axis of the anticline by the Ohio, Sterling, and other oil companies. According to recent reports, the Ohio Oil Co. has drilled two wells as deep as the "Red Beds" (Spearfish formation). One of these wells is in the SE. $\frac{1}{4}$ sec. 11, T. 39 N., R. 61 W., and the other is near the southwest corner of sec. 36, T. 40 N., R. 61 W. The company is now (January, 1920) considering drilling the latter well still deeper for the purpose of testing some of the lower sands. Both of these wells are called dry holes, and both are well located with respect to the axis of the anticline. Having reached the "Red Beds," they have penetrated the sand that produces oil on the eastern anticline. The horizon of the oil sand is much higher in the western anticline, as explained on page 48, and there is an extensive collecting area to the north and west, but the results of drilling seem to be rather discouraging. The failure to obtain oil near the top of the western anticline is probably due to a change in the thickness or porosity of the oil sand, but additional subsurface data are necessary before the problem can be satisfactorily solved.



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EXPLANATION

DEPARTMENT OF THE INTERIOR

JOHN BARTON PAYNE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 716—D

**NATURAL-GAS RESOURCES AVAILABLE TO
DALLAS AND OTHER CITIES OF
CENTRAL NORTH TEXAS**

BY

E. W. SHAW AND P. L. PORTS

**Contributions to economic geology, 1920, Part II
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NATURAL-GAS RESOURCES AVAILABLE TO DALLAS AND OTHER CITIES OF CENTRAL NORTH TEXAS.

By E. W. SHAW and P. L. PORTS.

NATURE OF THE PROBLEM AND PREVIOUS WORK.

The acute shortage of gas in Dallas and other cities in north Texas during the winter of 1919-20 led to an urgent request from Mayor Frank W. Wozencraft, of Dallas, that the United States Geological Survey make an examination of the gas resources of the region with a view to determining whether the shortage was due to exhaustion of underground supplies or to some nongeologic cause such as inadequacy of wells or transportation equipment, lack of proper adjustment of prices, or wasteful consumption.

In 1915 a similar call had come from the cities of Dallas and Fort Worth, and an examination of the principal source of supply—the Petrolia field—and other more or less productive or promising territory led to the conclusion that all known Texas fields as at that time developed would not fully meet the growing demand of these cities for more than a year or two and that it would be wise to extend the pipe lines to fields in southern Oklahoma. This was done, and as a result of the added supply thus made available and of the curtailment of industrial use the needs of the gas-consuming communities have been fairly well met for three years. The main conclusions set forth in the first report¹ are as follows:

PETROLIA FIELD.

Original quantity of gas in the field.—The volume of pore space occupied by gas and the original rock pressure and also the relation between decline in pressure and percentage of depletion indicate that the original quantity of gas in the Petrolia field, measured at 8 ounces above atmospheric pressure, was about 120 billion cubic feet.

Ratio between percentage of depletion and amount marketed.—Statistics of production indicate that about 37 billion cubic feet of gas from the Petrolia field have been delivered to consumers. This quantity is about 75 per cent of the reduction of supply in the ground. The question whether or not this per-

¹ Shaw, E. W., Matson, G. C., and Wegemann, C. H., Natural-gas resources of parts of north Texas: U. S. Geol. Survey Bull. 629, pp. 73-75, 118-119, 126, 1916.

centage should be larger is beyond the scope of this report, but it may be remarked that many gas fields show a greater waste.

Present capacity.—The Petrolla field as now drilled and equipped is capable of producing more gas per day than it has ever been called upon to produce. The limit of its daily capacity depends in part upon engineering considerations not discussed in this report, such as the handling of wells and pipe lines, but it is probably at least twice that of any demand which has been made upon it.

Capacity in near future of the field as now drilled.—The daily capacity of the wells in the field is steadily decreasing, and indeed the field as a whole is doubtless rapidly approaching its limit in rate of production. While the demands upon it have been steadily growing, its capacity has been diminishing because of reduction of supply and pressure, and before many years have passed the supply will no longer meet the demand.

Capacity in distant future of the field as now drilled.—If no new gas wells were drilled the production would not only fall below the demand in a few years, but in 10 years the output would probably be too small to be worth transporting.

Increase of capacity through new wells to known sands in the proved field.—The capacity of the field may be kept up for a few years by new wells drilled to known sands within the proved field, but the present wells are rather evenly distributed and closely spaced, so that increase of output through new wells can not be great.

Increase of capacity through finding new sands in the proved field.—More gas can probably be found in some parts of the field by drilling deeper, for sands having favorable structure, texture, and stratigraphic and lithologic relations lie below the sands now producing. A few small gas-bearing lenses of sand lie above the producing sand, and though these lenses contain much less gas than the so-called deep sands they should not be overlooked.

Increase of capacity through finding new productive area adjoining the field.—The daily capacity of the field may be increased by new wells drilled outside the proved field to sands now producing. The structure of the field indicates that the actual area of the gas pool is probably twice that of the area now producing, though a part of the new area may yield oil instead of gas. The production can not, of course, be doubled by simply doubling the producing area, for gas has been slowly moving from the undrilled ground to the producing wells, so that throughout most if not all of the undrilled parts of the pool the original gas content and pressure in the sands have been reduced, though not so greatly reduced as in the developed part of the pool.

Increase in marketed supply through greater care in handling wells.—The depletion of the original supply of gas at Petrolla is evidently considerably greater than the quantity of gas marketed, the loss incidental to the production of oil being especially noteworthy. The output could be increased by handling the wells somewhat differently, but the work of properly caring for the natural supply must be left to the engineers.

Life of the field.—If all the gas at Petrolla could be delivered to consumers in Dallas and Fort Worth and other cities now drawing on the Petrolla supply it would probably last them, at the present rate of consumption, about $6\frac{1}{2}$ years. If an estimate is made of the increase in consumption that will probably occur if the supply is adequate and no advance is made in the price, proper deduction being made for necessary losses in production and marketing, the estimate of $6\frac{1}{2}$ years must be reduced to about 4 or 5, and if further allowance be made for unnecessary losses, it must be reduced to 3 or 4 years, and a shortage will be felt in cold weather still sooner.

OTHER FIELDS.

Other discovered pools northwest and west of Dallas and Fort Worth, particularly those at Strawn and Moran, have noteworthy quantities of gas, though not so much as Petrolia, and these supplies would be available to the cities if the pools were near to each other or to the existing pipe lines.

Undiscovered pools of gas and oil undoubtedly exist in the area described in this report, and some of them will probably be large enough to warrant the building of individual pipe lines. If several of them were developed at once, however, sufficient gas would be made available to justify the construction of lines to groups of pools. The search for new pools must be pushed with vigor if the present output is to be maintained or increased.

* * * * *

Gas has been found at Baileyville, Koose, Thornton, Groesbeck, Mexia, Wortham, Currie, Richland, Corsicana, Powell, Chatfield, Mabank, Cash, and Cooper. At only three of these places have wells furnished gas in commercial quantities, and at only two have wells furnished oil, but the significance of the presence of gas in the area between Baileyville and Cooper is not affected by the commercial value of the discoveries that have been made. These discoveries show the presence of gas-bearing sands through this belt, and investigations indicate that the dip of the beds here is not uniformly toward the southeast but is interrupted by terraces and minor reversals of dip. Structure favorable to the accumulation of oil or gas, similar to that at Mexia, Groesbeck, Powell, and Corsicana, will no doubt ultimately be discovered in this region, which is therefore regarded as a possible oil and gas field.

* * * * *

CONCLUSIONS REGARDING OKLAHOMA.

In conclusion, it may be stated that the gas resources of central and southern Oklahoma are sufficient, if protected from waste and properly handled, to furnish supplies to such cities as Dallas and Fort Worth for years to come. The gas is, however, for the most part distributed over large areas in many pools of comparatively small size, and it may prove unprofitable under present conditions to build pipe lines of sufficient extent to collect it. Among the larger gas pools may be mentioned the field south of Checotah, in McIntosh County, which is at present being drilled. The large supplies of gas in the immediate vicinity of the Healdton oil field are worthy of careful consideration, especially since the bringing in of the new gas well near Fox, north of the field, which suggests the possibility of the presence of other gas pools in this vicinity.

In 1918 an estimate of the quantity of gas remaining in the Petrolia field was made by G. S. Rogers,² in connection with an investigation of the helium resources of the country. Rogers examined critically the data and methods used by Shaw three years before, checked the results, with the help of new facts gained from the behavior of the field in the intervening period, and concluded that Shaw's estimates of original reservoir capacity and quantity remaining in 1915 were correct and that in July, 1918, between 13 and 20 billion cubic feet remained in the pool. He remarks that if the remaining gas were used at an average rate of 15,000,000 cubic feet a

² Rogers, G. S., Helium-bearing natural gas: U. S. Geol. Survey Prof. Paper 121 (in press).

day the field would last two and one-half to three years. Since his estimate was made, however, the Lone Star Gas Co. has contracted with the Navy Department to reduce the output of the field to 10,000,000 cubic feet a day. Also since that time gas has been discovered on the Martin farm, about 2 miles west of the main part of the field, and the question has arisen whether the Martin wells are to be regarded as being in the Petrolia field, and whether their gas is a part of that in the Petrolia pool.

The evidence at present available indicates that in the middle of 1918 there was 20 to 25 billion cubic feet of recoverable gas in the Petrolia pool, including the Martin gas, and that at the end of March, 1920, there remained 8 or 10 billion cubic feet of recoverable gas, for at that time the entire field seemed to contain only 12 to 15 billion cubic feet of gas, and of this about 4 or 5 billion cubic feet will never reach the consumer, for the reason that some will be left underground and some lost on its way to market. The method of computation is outlined on the following pages.

In the matter from the previous report quoted above it is concluded on the basis of geologic evidence that undiscovered pools of gas and oil undoubtedly exist in the region, and in the text and figure on page 20 of that report the favorable general structure west of Fort Worth is pointed out. Since Bulletin 629 was published the great oil and gas bearing territory centering around Ranger has been developed, and the question arises, What relief may Dallas and other communities suffering from gas shortage expect from these fields? The conclusion reached in the present report is that the discovered fields contain enough gas to supply the domestic demands of these communities for several years, and that there are undoubtedly still some undiscovered gas pools in the region.

A preliminary summary of the present situation was contained in a telegram from the Director of the United States Geological Survey to Mayor Wozencraft on February 3. The results of the investigation harmonize with this summary but allow particularization where at first only generalization was possible. The telegram follows:

Gas resources north Texas, although limited and being rapidly depleted, are not yet nearing exhaustion. If a well-considered drilling program be followed, adequate pipe line and compressors be installed, waste reduced, and industrial consumption eliminated, remaining supplies will meet needs of residences in Dallas and other cities now served probably five to ten years. With industrial consumption in summer cost of domestic service would be somewhat lower than otherwise, but life of fields would be correspondingly shortened. Geologic conclusions of full report will therefore probably be favorable, for apparently Texas still has considerable gas, though it would have had much more if waste had been kept within reasonable bounds. Engineering problems of gathering and transporting gas and economic problems of rates, restrictions in classes of use,

reduction of peak load, and general conservation will then remain to be solved, though it is fairly obvious that gas can be supplied for a few years at prices and in quantities that will enable it to compete successfully with other fuels.

In a later telegram to Mayor Wozencraft dated February 25 the Director stated:

Conclusions will doubtless show sufficient gas economically available for several years' domestic demand. Petrolia, best pool yet discovered, now probably 90 per cent exhausted. West Texas pools promising but need careful development, pipe lines, compressors, and reduction of waste. Capacity southern Oklahoma pools medium to small, but their aggregate volume sufficient to supply reduced demand at least two years. Undoubtedly several important undiscovered pools in Texas, but several years necessary to find and develop them. Great need is reduction of waste and determination by business men of price for fair return to invested capital under good management to stimulate search for gas independent of oil and to conserve the large but limited supplies.

ACKNOWLEDGMENTS.

The citizens of north Texas and in particular the officials of the city of Dallas and those of the Lone Star Gas Co. cooperated heartily in every way possible toward the success of the work. Mayor Frank W. Wozencraft and Chief Engineer Ed C. Connor were especially helpful. The officers of the Lone Star Gas Co., the Dallas Gas Co., and the Fort Worth Gas Co. allowed free inspection of their records, supplied maps, and assisted in making observations and collecting data. Numerous geologists and others connected with different companies have been called upon for aid, and all have assisted without reserve. Robert T. Hill, who has done many years of effective work on Texas geology, rendered especially valuable assistance.

LOCATION AND AREA.

The region in which Dallas and other cities are interested as a source of natural gas may be arbitrarily defined as that portion of Texas lying east of the 100th meridian and north of the 31st parallel, together with the southern two tiers of counties in Oklahoma, or it may be said to include all territory within 200 miles of Dallas. (See Pl. VIII.) The assignment of precise limits is impracticable and unsatisfactory, for the reason that the availability of a gas supply depends not only on distance from points of use but on other factors, such as magnitude and compactness of market. The business of producing and marketing natural gas involves not only the cost of gathering, transporting, and distributing the gas and ordinary overhead expenses but provision to meet an irregular demand. As the underground supply in any field is not unlimited the expenses of these several classes must be distributed equitably over the supply available. Pipe lines alone commonly cost more than \$25,000 a mile and

depreciate so fast that they may have to be replaced within a few years. The salvage of pipe and other equipment on the exhaustion of the gas supply is often very expensive. If the underground supply is large and occurs in a small area and if the gas sand is thick and large-pored, so that the wells yield a large amount per day, gathering costs will be correspondingly low. If the closed pressure is high and the supply large, compressing and transportation costs will tend to be low. If there is a demand for a large amount of gas at the delivery end of the pipe line and along its course, if the consumers require large quantities per day, and if the points of consumption are close together, or if there are many good-sized towns along the line, costs will tend to be low. The cost of reading meters and collecting bills is lower per thousand cubic feet for the large consumer than it is for the small consumer. Lastly, if there is a great variation in demand per day, pipe and other equipment must be installed for the peak demand, and the unit cost of service will be higher than if the demand were uniform.

These nongeologic considerations are cited to emphasize the fact that the geologic problems of existence, location, extent, and compactness of underground supplies and character of the reservoir are only a few of the factors that enter into the business problem of whether or not the supplies can be got to market for a price per thousand cubic feet that the consumer is willing to pay. Natural gas has been transported with profit to markets considerably farther than 200 miles from the source of supply, but this has been done under favorable circumstances, such as a large quantity of available gas, many cities and towns along the line, and good-sized cities at the end of the line. Perhaps the most noteworthy example has been the transportation of West Virginia gas to cities in Indiana. The gas at Mexia is less than 100 miles from Dallas, but it can not be brought to Dallas at a profit because the amount is small. Indeed, it would not pay the cost of transportation and marketing if the quantity were several times as great as has been discovered up to the present time. On the other hand, if northwestern Louisiana, 200 miles from Dallas, had a large surplus, or even if the Amarillo field, 350 miles distant, included several very large pools in open-pored sands, it might be feasible to bring gas from these sources to Dallas.

The general problem, with one or more phases of which this paper has to do, is in part an examination of the prospects of finding new fields, in part an appraisal of known pools not yet connected with the pipe-line system, and in part the determination of means of adjusting the diminishing supply of natural gas in the old fields to the increasing needs of rapidly growing cities. When the gas fields of north Texas were first called upon to serve Dallas and other cities, the supply of gas in sight appeared to be ample for years to come.

Now, even though additional supplies have been found, the growth in population, with the consequent increase in the number of gas consumers, has overtaken the rate of new production, and an acute shortage is felt.

The cities and towns of north Texas now using natural gas for fuel and lighting are Petrolia, Fort Worth, Bellevue, Bowie, Sunset, Alvord, Decatur, Rhome, Bridgeport, Irving, Arlington, Dalworth, Dallas, Gainesville, Sherman, Denison, Whitesboro, Denton, and McKinney, which receive their supply through one company, the Lone Star Gas. Co. of Dallas, and Electra, Burkburnett, Abilene, Albany,

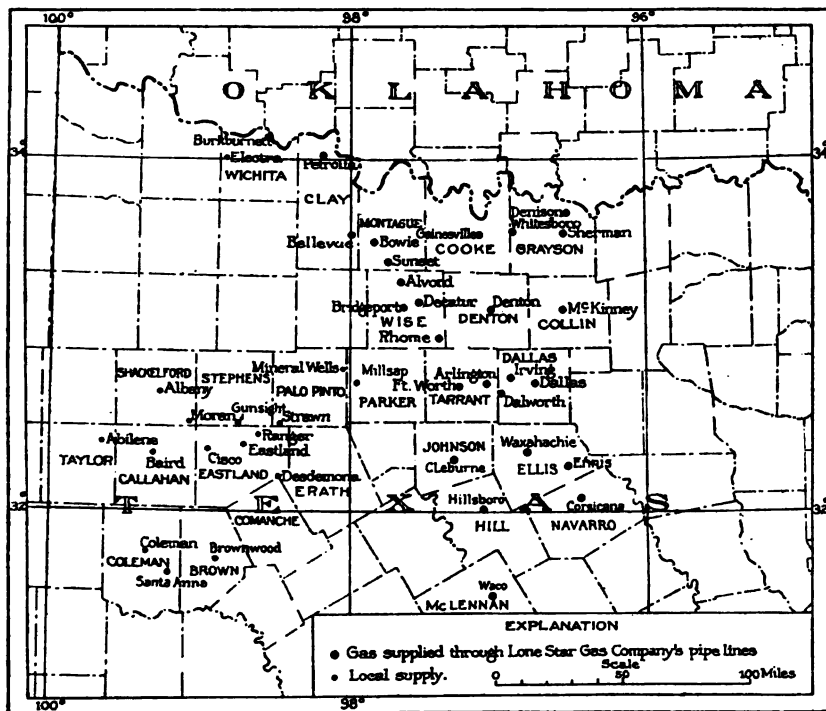


FIGURE 2.—Map showing cities and towns in north Texas using natural gas.

Moran, Mineral Wells, Baird, Cisco, Eastland, Ranger, Thurber, Desdemona, Coleman, and others, which are served by local producing gas companies and are supplied by near-by fields. (See fig. 2.)

FIELDS NOW SUPPLYING NORTH TEXAS.

PETROLIA FIELD.

HISTORY AND PRESENT CONDITIONS OF DEVELOPMENT.

The first important gas field to be developed in north Texas was the Petrolia field of Clay County. Although it had been known as an

oil field for some years, its development as a gas field did not begin until October, 1907, when the first gas well was brought in. The next year two other gas wells were drilled, furnishing an ample supply for the town of Petrolia, about 2 miles distant, and for drilling operations in the field.

By 1909 the gas development had reached a stage that demanded a greatly enlarged market, and a 16-inch pipe line was laid to Fort Worth and Dallas, respectively, 94 and 135 miles away. About the same time service was extended to Wichita Falls, 18 miles from Petrolia. This field furnished the entire supply of gas for a large number of towns in north Texas until the southern Oklahoma fields were connected with the system, in November, 1917.

The gas from the Petrolia field is supplied to Dallas and Fort Worth through a 16-inch line, and to Wichita Falls through one 6-inch and one 8-inch line. The natural pressure of the gas is insufficient to force it through the pipe line in the quantities required, so a battery of five large compressors, each of 1,250 horsepower, has been installed at the Petrolia compressing station. The gas is compressed in two stages, first to a pressure of about 40 pounds to the square inch, and then to about 150 pounds, at which it is delivered into the lines. The low-stage compressors apparently do not raise the pressure above the average rock pressure. As a matter of fact, however, they produce a suction so that the pressure at their intake valves is only about 1 pound. This produces a differential between that point and the mouth of the well. Otherwise the gas would not flow in sufficient volume to feed the compressor. It should be noted, too, that at present many of the wells have a rock pressure very little above zero.

MODE OF OCCURRENCE OF THE GAS.

Most natural gas occurs in porous layers or strata of sandstone; some, however, is found in limestone and other kinds of rock. The strata lie in general more or less nearly horizontal but in detail have an undulating or wrinkled form. The pay "sands," as the beds containing the gas are called, are usually overlain and surrounded by closer textured rock which prevents the escape of the gas. Wrinkles or arches of approximately circular form are called domes; those of elongated outline are called anticlines. Innumerable variations and combinations of these forms occur. Where oil is associated with the gas, it is generally found below the gas, presumably because of its higher specific gravity; where water is present it commonly forms the lowest member of the series, for the same reason.

Examinations of specimens of the producing sands of the Petrolia field made in connection with Shaw's investigations in 1915 showed that they have an average porosity between 20 and 25 per cent. In

this field there are three principal producing sands, at different levels or horizons; their aggregate thickness is 30 to 40 feet. The total area underlain by these producing sands, as outlined more or less clearly by dry holes, considered in connection with the structure as inferred from well records and from surface outcrops, is 12 to 15 square miles. With these data at hand it is a simple matter to compute the space originally occupied by the gas. At the time of the earlier estimate the average thickness of the pay sands was inferred to be 30 feet, the pore space 20 per cent, and the areal extent of the pool 15 square miles. From these figures the apparent total original volume of the reservoir was computed as about 2,500,000,000 cubic feet. Later developments and fuller knowledge tend to indicate that the average thickness of pay sands is perhaps a little more than 30 feet, the pore space possibly somewhat more than 20 per cent, the area underlain by gas-bearing strata less than 15 square miles, and the original volume of the reservoir about 2,250,000,000 cubic feet.

PREVIOUS ESTIMATES OF GAS RESERVES.

The entire amount of gas originally present in the Petrolia field was estimated by Shaw in 1915 to have been about 120 billion cubic feet, measured at a pressure of 8 ounces to the square inch, the pressure at which gas is normally supplied to city consumers. The space underground in which the gas was stored was computed at 2,500,000,000 cubic feet, as indicated above. The gas is thought to have been originally under a pressure of about 725 pounds to the square inch, the average pressure shown in the first wells drilled. Applying the well-known law of Boyle, according to which the volume of gas is inversely proportional to the pressure to which it is subjected, and adding atmospheric pressure to each of the pressures stated above, we obtain the ratio of 740:15.5, or roughly 48:1. Thus the reservoir whose total capacity was approximately 2,500,000,000 cubic feet contained gas enough at a pressure of 725 pounds to the square inch to occupy 120 billion cubic feet at a pressure of 8 ounces to the square inch. Later developments and additional facts indicate a total volume of about 110 billion cubic feet (see p. 66), but the probable degree of correctness of the earlier figures is remarkably high considering the hazardous nature of attempts to estimate quantities of underground gas.

In 1918 Rogers made an estimate of the quantity of gas then remaining in the Petrolia field, and concluded that Shaw's earlier inferences as to the original capacity of the reservoir and the volume of gas contained in it were both correct. Some of Rogers's conclusions are as follows:

1. A study of the curve showing decline in rock pressure indicates that at the present rate of production the field will be exhausted at the end of 1920,

but that if the production is decreased to 12 or 15 million cubic feet a day the field will probably last at least a year longer, provided water does not invade the gas sands.

2. An estimate of the quantity of gas remaining in the ground indicates that 13 to 20 billion cubic feet is still available, or a supply of 15 million cubic feet a day up to some time in the year 1921.

3. There is reason to believe that a small pool may be found about 2 miles west of the field.

It is worthy of special note that Rogers clearly foretold the discovery of the Martin gas.

NEW ESTIMATE OF QUANTITY OF GAS REMAINING.

The total amount of gas marketed by the Lone Star Gas Co. from the Petrolia field from 1910 to 1919, inclusive, is shown in the following table:

Rock pressure, open-flow capacity, and production of Petrolia field, including Martin wells, 1910-1919.

Year.	Average rock pressure Jan. 1.	Open flow Jan. 1.			Gas marketed during the year by Lone Star Gas Co. (thousand cubic feet).
		Number of wells tested.	Combined open flow (thousand cubic feet).	Average per well (thousand cubic feet).	
1910.....					1,583,080
1911.....					5,175,196
1912.....	659				7,186,322
1913.....	621				10,089,135
1914.....	511				9,683,293
1915.....	318	41	365,090	8,904	8,999,837
1916.....	239	43	272,345	6,484	8,945,522
1917.....	174	46	190,503	4,141	6,101,167
1918.....	87	45	75,855	1,696	5,579,088
1919.....	54	43	34,604	1,081	3,602,686
1920.....	65	34			

The total quantity of gas marketed from the field can not be stated with precision, but for 1915 to 1919, inclusive, it ranged from 7 to 10 billion cubic feet annually. The quantity produced from 1907 to 1910 is not known but may be estimated at about 10 billion cubic feet.

The decline in closed pressure is illustrated in figure 3 and that in open-flow capacity in figure 4.

The amount of gas lost from the reservoir but not marketed is not known, but enough data are available to make possible an estimate of value. It is known that for the United States as a whole more gas has been lost than has been marketed—that the underground loss plus the loss from blowing off wells plus the quantity used more or less efficiently in the field but not sold, plus the large quantity lost along gathering lines, main lines, and distributing lines amounts to more than all the gas that has been delivered to both industrial and

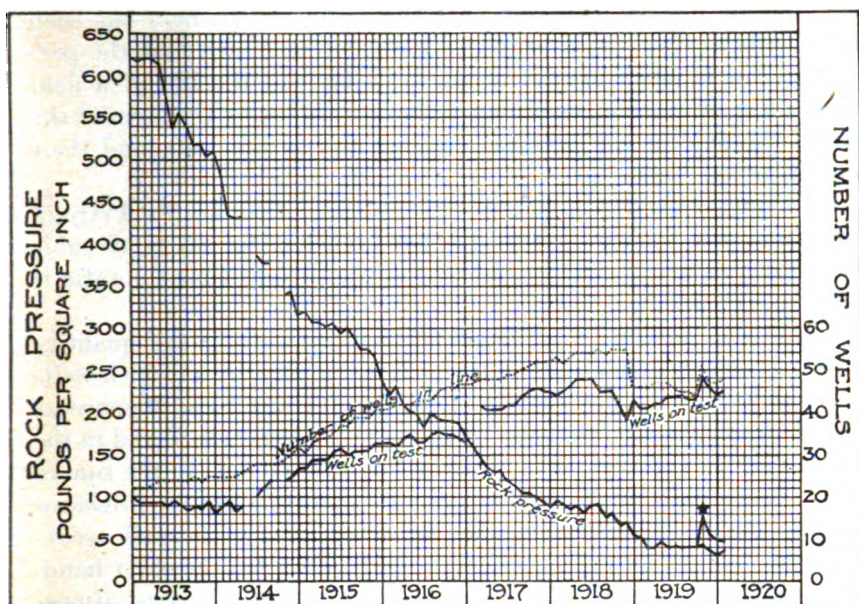


FIGURE 3.—Curve showing decline in rock pressure, number of wells in line, and number on test in Petrolia gas field, Tex. Curve marked ★ represents seven new wells in Martin field, rock pressure 50 to 605 pounds.

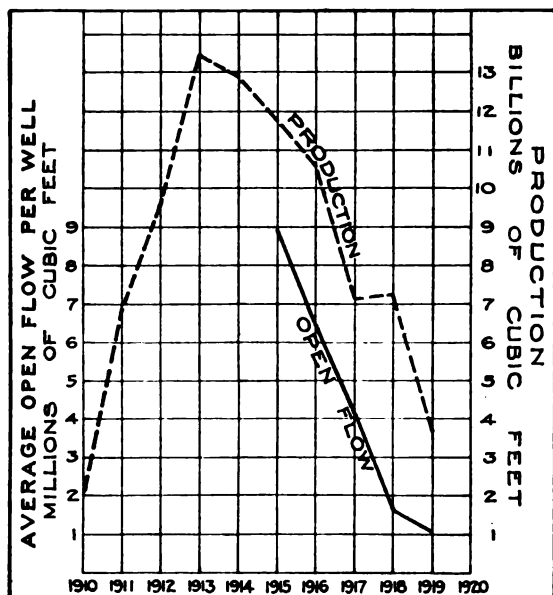


FIGURE 4.—Curve showing decline in open flow per well and total production in Petrolia gas field, Tex. Open-flow tests made January 1 of each year.

domestic consumers. It is evident from a study of the Petrolia gas field and its history, however, that the waste in this field has been considerably below the average. Finally, it is known that the percentage lost is much greater at the beginning of the life of a field than at any other time, declining rather continuously throughout the life of the field as the pressure declines and as the wells and their equipment are improved.

All things considered, it may be estimated that in the Petrolia field from 3 to 6 cubic feet of gas has been lost for every 10 cubic feet delivered to a consumer and that at the present time the ratio is still lower than this.

Another consideration of importance in estimating the quantity of recoverable gas remaining in the pool is the pressure at which wells are abandoned. In the Petrolia field the average rock pressure at abandonment has been perhaps 3 pounds to the square inch and in the future may be expected to average as low as 2 pounds to the square inch. Some wells have been abandoned at much higher pressures because they were "drowned out" by water, and occasional occurrences of this sort may be expected in the future. On the other hand, some wells will produce until the pressure has declined to atmospheric pressure, and some will no doubt be pumped until it is considerably lower still.

The problem of estimating the gas remaining in a field may be worked out as indicated below. The underlying principle of this solution is, of course, Boyle's law.

Let V = volume of gas originally in the field.

v = volume of gas not recoverable.

v' = volume of gas in field at any particular date.

$v' - v$ = gas recoverable at the date indicated.

R = original rock pressure.

r = rock pressure at time of abandonment.

r' = rock pressure at the date indicated.

p = atmospheric pressure.

$$v = \frac{(r+p)V}{(R+p)}$$

$$v' = \frac{(r'+p)V}{(R+p)}$$

$$v' - v = \frac{(r' - r)V}{(R+p)}$$

The quantity of gas recoverable in the Petrolia field January 1, 1920, is computed from these formulas as follows:

V = 110 billion cubic feet, original volume (revised estimate).

R = 725 pounds, original rock pressure.

$r'=85$ pounds, rock pressure January 1, 1920 (average for entire sand).

$r=2$ pounds, rock pressure at which field is abandoned.

$p=14.4$ pounds, atmospheric pressure.

$v'-v=10,900,000,000$ cubic feet.

This is the theoretical quantity of gas recoverable and does not allow for losses or for the effect of water encroachment. The losses may be estimated at 20 to 25 per cent.

WATER ENCROACHMENT.

The past and probable future extent of water encroachment in the Petrolia field can best be inferred from the behavior and distribution of wells that have partly or wholly "gone to water." Eleven wells have been abandoned on account of flooding, and five wells are at present showing more or less water. The total number of gas wells drilled in this field is about 79, of which 48 are now producing.

The mode of water encroachment is fairly clear from a study of the individual wells that have "gone to water." Beatty No. 1, north of the center of the field and considerably off the structural axis, was abandoned about January, 1918, at a rock pressure of 90 pounds. Skelly No. 2, south of the Beatty well and near the highest part of the sand, was abandoned as early as 1913 at a pressure of 300 pounds. Other wells in other parts of the field were abandoned at pressures of 0, 50, 90, and 120 pounds. These observations indicate that water is advancing into the gas reservoir but that the principal mode of advance is from below up rather than from the borders inward.

The wells that have "gone to water" are not scattered indiscriminately over the field but are distributed in more or less well-defined groups. (See Pl. IX.) The order in which water troubles developed in the Miller and Donley wells, on the south edge of the field, indicates that water is creeping up the south flank of the dome. On the other hand, some of the earliest wells to be drowned out were near the top of the dome. In these wells, however, water from higher strata may have entered through faulty packing and penetrated the producing sand. The effects of water encroachment, though serious, are local, and the field as a whole is not being systematically inundated.

In view of the facts above stated some allowance should obviously be made for the retardation of the decline in closed pressure caused by water advancing into the gas reservoir. Apparently the area of the gas pool has been reduced by 1 or $1\frac{1}{2}$ square miles, and the capacity of the reservoir has been correspondingly reduced, being now about 90 per cent as great as it was originally, if the sands are fairly uni-

form in thickness. At least 10 per cent should therefore be deducted from the estimate of 10,900,000,000 cubic feet given above, leaving 9,810,000,000 cubic feet as the estimated quantity of gas that in the future can be delivered into the mains from the Petrolia field.

There is no way of determining the future rate of water encroachment except by inference based upon the probability that a fairly uniform rate of flooding will be maintained and that wells near those already flooded will go out in their turn. As the rate of general depletion of the field has far exceeded the rate of water encroachment, it is not probable that any large portion of the remaining supply will be cut off by this agency.

MARTIN WELLS.

The relation of the Martin wells to the main part of the Petrolia field is not definitely established and promises to be a matter of considerable controversy. In the foregoing discussion they are regarded as constituting a part of the Petrolia field for reasons set forth in the following paragraphs.

The wells are on the N. H. Martin farm, about 3 miles southwest of Petrolia. There are four producing gas wells, and a fifth is nearing completion.

Data concerning the Martin wells.

Name.	Date completed.	Total depth (feet).	Depth of producing sand (feet).	Initial closed pressure (pounds to the square inch).	Initial open flow capacity (cubic feet).	Notes.
Martin No. 5.....	May 31, 1918	1,788	a 1,671-1,683 b 1,782-1,788	510	5,570,000	Making water and oil.
Martin No. 7.....	Jan. 27, 1919	.....	.....	.....	8,500,000	
Martin No. 9.....	Oct. 14, 1919	1,740	.....	605	38,800,000	
Martin No. 10.....	.....	.....	.....	.....	.....	
Martin No. 11.....	Feb. 20, 1920	1,710	a 1,683-1,693 b 1,713-1,720	425 510	8,277,120 14,844,976	

a Upper sand.

b Lower sand.

Sufficient data are not at hand for a complete and satisfactory computation of the total volume of gas for each sand, and the following figures must be regarded as tentative. It seems almost certain from the available well data that the structure precludes any great extension of the present pool toward the north, east, or south, and that extensions toward the west are problematic, with the best prospects toward the northwest. The fairly rapid decline of closed pressure with moderate output supports the inference that the reservoir is small.

Apparently the wells are drawing gas from an area of about $1\frac{1}{2}$ square miles. The sands seem to have an average total thickness of about 18 feet, and on the assumption that their pore space amounts to 20 per cent and that the original closed pressure was 550 pounds, the total volume of gas present would have been 5,500,000,000 cubic feet. This estimate seems to be moderate, and there is reason to believe that more complete data will raise rather than lower the figure. The gas marketed from these wells from November, 1919, to February 1, 1920, amounted to 937,081,640 cubic feet. It seems probable that several hundred million cubic feet additional has been drawn from the pool but for various reasons unmarketed. The original volume of gas has probably been reduced by 1,500,000,000 cubic feet. The decline in closed pressure of the wells has been nearly 50 per cent, but it is thought that at a distance from the wells the pressure is much higher, especially as the gas has been withdrawn so rapidly that the pressure has not had time to become equalized.

POSSIBILITY OF NEW POOLS.

Other outlying pools or arms of the main pool may be discovered. About 30 wells have been drilled in the territory immediately around the Petrolia pool, in a belt wide enough to include the Martin wells, and seven of these became producing oil or gas wells. This result would give a ratio of dry holes to producing wells of 4 to 1, and would suggest that extensions and new marginal pools should be sought at a greater distance.

The deep test well of the Lone Star Co., Byers No. 36, just west of the producing area, disclosed the fact that the strata underlying the known producing sands are similar in character and arrangement to those above, though at this point the whole series was barren. It might be well to drill a deep well in the center of the field at the southwest corner of block 5, near Culbertson well No. 5, which appears to have struck the "lime" near its highest point. This would be approximately at the center of the dome.

Very few if any undrilled locations still lie within the known limits of the pool. A study of the map and other data leads to the suggestion that a well be drilled about the center of block 16. The suggested location would be about 2,250 feet southeast of Landrum wells Nos. 1 and 2, which have declined in rock pressure at a uniform rate from 295 pounds in 1915 to 40 pounds at the present time. The suggested location would be 2,600 feet northeast of Jackson well No. 1, which was abandoned several years ago; 3,000 feet northwest of Holloway well No. 8, which came in at 110 pounds in 1918 and now registers

zero; and about the same distance northwest of Holloway No. 9, which came in at 140 pounds in 1918 and now has a pressure of 35 pounds. The best that could be expected from this location would be a well with a pressure of perhaps 50 pounds and a relatively small open flow.

Curves showing the decline in rock pressure and open flow for the Petrolia field are given in figures 3 and 4. Records of production are also shown for comparison in figure 4.

SUMMARY FOR PETROLIA FIELD.

Below is a summary of conditions in the Petrolia field, including the Martin wells, at three different periods in the history of the field:

1907.

Original closed pressure of pool, pounds to the square inch	725
Original absolute pressure of pool (=gage reading+atmospheric pressure)-----pounds to the square inch	740
Area of pool-----square miles	12-15
Average thickness of pay sand-----feet	30-40
Average pore space of pay sand-----per cent	20-25
Original capacity of reservoir (revised estimate), billion cubic feet	24
Original gas content measured at 8 ounces above atmospheric pressure (revised estimate), billion cubic feet	110

September, 1915.

Average closed pressure of active wells, pounds to the square inch	288
Average pressure midway between wells, pounds to the square inch	375±
Average pressure in marginal territory and in lenses having poor connection with wells, pounds to the square inch	650±
Average pressure through entire pool, pounds to the square inch	435
Average absolute pressure for entire pool, pounds to the square inch	450
Quantity of gas marketed-----billion cubic feet	37
Estimated quantity of gas lost-----do	13
Estimated quantity of gas remaining (allowing for some water encroachment)-----billion cubic feet	70

February, 1920.

Average closed pressure of active wells in old Petrolia field.....	pounds to the square inch...	49
Average closed pressure of Martin wells.....	do...	305
Average pressure midway between wells in old Petrolia field.....	pounds to the square inch...	70±
Average pressure in marginal territory and in lenses having poor connection with wells.....	pounds to the square inch...	175±
Average pressure through entire pool including Martin farm.....	pounds to the square inch...	85±
Average absolute pressure for entire pool.....	do...	100
Estimated quantity of gas marketed.....	billion cubic feet...	70-80
Estimated quantity of gas lost.....	do...	20-25
Estimated quantity of gas remaining (allowing for some water encroachment).....	billion cubic feet...	12-15
Estimated future underground loss, including gas finally left in sand and that lost to other sands, billion cubic feet.....		2-3
Estimated future loss above ground.....	billion cubic feet...	1-2
Estimated quantity of gas remaining in pool, including Martin wells, that can be delivered to the mains, billion cubic feet.....		9-10

FOX FIELD.**GENERAL FEATURES.**

The Fox field is in Tps. 2 and 3 S., Rs. 2 and 3 W., Carter County, Okla., about 10 miles north of the Healdton oil field, where there are several gas wells, one of which had an initial open flow of 40,000,000 cubic feet a day. The gas at Healdton, being considered of secondary importance to the oil, has not been conserved. In November, 1917, a 16-inch gas line was laid to Dallas from the southeast corner of Stephens County, Okla. This line is about 115 miles long. From its northern extremity an extension of 12-inch pipe, 8½ miles in length, taps the Fox field.

The Fox field now contains 12 wells, the first of which, northwest of the village, was completed in October, 1915. This well had an initial daily open flow of 18,000,000 cubic feet. The average daily open-flow capacity of the producing wells in the field on February 1, 1920, was 7,700,000 cubic feet. As many as five producing sands, all of which are believed to be of Pennsylvanian age, are penetrated in some of the wells. These sands range in depth from 1,400 to 2,300 feet. One or two wells produce from shallow sands less than 1,000 feet deep. A typical well log showing the relative position of the five sands is given below.

Typical well log of Fox field, Okla.

[Trucker No. 1, Phillips Petroleum Co., sec. 29, T. 2 S., R. 3 W. Drilled June 16, 1918. Rock pressure 695 pounds to the square inch. Open flow 33,900,000 cubic feet a day.]

Formation.	Color.	Hardness.	Thickness (feet).	Depth (feet).	Remarks.
Surface	Gray	Soft	6	6	
Sand	White	do.	27	33	
Red bed	do.	do.	32	65	
Shale, sandy	Gray	do.	40	105	
Rock	Red	do.	8	113	
Sand	White	do.	25	138	
Rock	Red	do.	10	148	
Sand	White	do.	12	160	
Rock	Red	do.	25	185	
Sand	White	do.	24	209	
Rock	Red	do.	28	237	
Sand	White	do.	28	265	
Sand	Red	do.	85	350	Fresh water at 138 feet.
Sand	White	do.	10	360	
Rock	Red	do.	45	405	Fresh water at 360 feet.
Sand	White	do.	45	450	
Rock	Red	do.	135	585	
Sand	White	do.	20	605	
Shale	Blue	do.	45	650	
Shale, sandy	do.	do.	50	700	
Rock	Red	do.	125	825	
Sand	White	do.	40	865	
Rock	Red	do.	7	872	
Shale	Blue	do.	103	975	
Rock	Red	do.	60	1,035	
Shale	Blue	do.	15	1,050	
Rock	Red	do.	10	1,060	
Shale	Blue	do.	44	1,104	
Sand	White	do.	100	1,204	
Shale	Blue	do.	26	1,230	Dry sand.
Sand	White	do.	55	1,285	Do.
Shale	Blue	do.	20	1,305	
Sand	White	do.	7	1,312	
Shale	Blue	do.	8	1,320	
Shale, sandy	do.	do.	10	1,330	
Shale	do.	do.	50	1,380	
Sand	White	Hard	90	1,470	
Shale	Blue	Soft	20	1,490	
Do	Brown	do.	20	1,510	
Do	Blue	do.	35	1,545	
Lime	White	Hard	15	1,560	
Shale	Blue	Soft	35	1,595	
Lime	White	Hard	23	1,618	
Gas sand	do.	do.	32	1,650	
Shale	Blue	Soft	13	1,663	1,500,000 cubic feet of gas.
Sand	White	do.	10	1,673	Dry.
Shale	Blue	do.	27	1,700	
Dry sand	White	do.	44	1,744	
Gas sand	do.	do.	3	1,747	
Shale	Brown	do.	10	1,757	
Gas sand	White	Hard	5	1,762	
Lime shell	Brown	do.	8	1,770	
Shale	do.	Soft	28	1,798	
Sandy lime	Gray	Hard	6	1,804	
Shale	Brown	Soft	31	1,835	
Sandy lime	Gray	Hard	6	1,841	
Shale	Brown	Soft	9	1,850	
Sharp sand	White	Hard	40	1,890	33,000,000 cubic feet of gas.

PRODUCTION.

The average closed pressure in the Fox field in November, 1917, was about 720 pounds to the square inch. By February, 1920, it had fallen to 141 pounds. (See fig. 5.) This decrease would indicate that the field is at present about 80 per cent depleted. The gas marketed from this field since November, 1917, amounts to about 17 billion cubic feet. All things considered it may be inferred that

about 5 billion cubic feet can in the future be recovered and marketed from this field. A separate estimate of losses and of gas used in field operations is not needed for this preliminary estimate, because it is probable that the proportion of such gas to the total withdrawals from the pool will not change materially in the future. Any estimate must be regarded as tentative, for the available data concerning area, thickness, and porosity of sands, etc., are not as full as could be de-

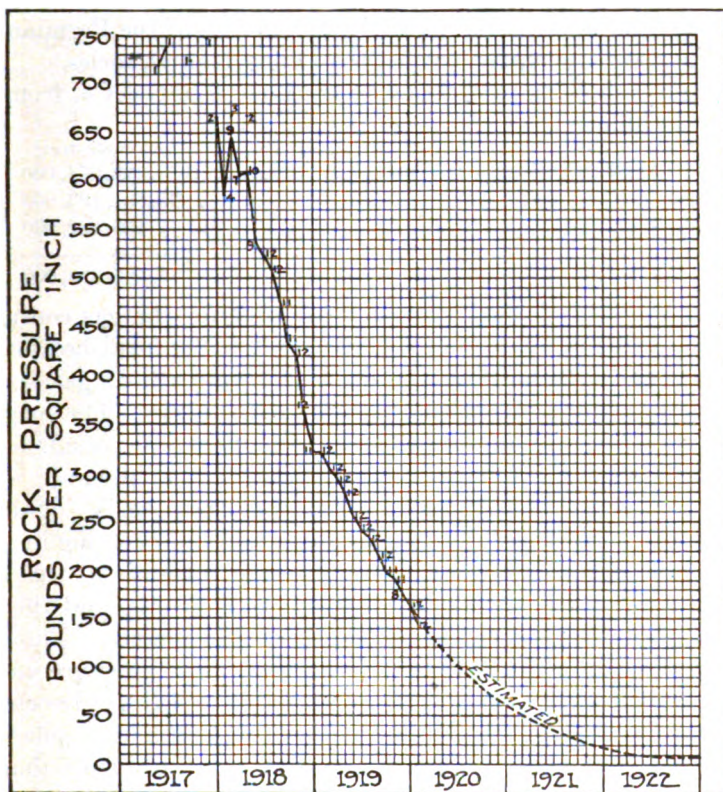


FIGURE 5.—Curve showing decline in rock pressure in the Fox gas field, Okla. Figures on curve indicate number of wells tested.

sired, and there is always the chance of considerable error in determining underground gas reserves.

There is a reasonable hope that the field may be extended, and much prospecting is now being done in adjacent areas.

WALTER FIELD.

The Walter or Keys field lies in the northeast quarter of Cotton County, Okla., north of the town of Walter. The field supplies both oil and gas, many of the wells coming in as gas wells and later yielding oil. The highest recorded initial rock pressure was 825 pounds

to the square inch. The Sanders well No. 1, in sec. 3, T. 2 S., R. 10 W., and the Skelton well No. 1, in sec. 1, T. 2 S., R. 11 W., came in at that pressure. Each of these wells had an open-flow capacity of about 18,000,000 cubic feet a day. Several of the wells had a greater initial capacity, but the average for the field is about 10,000,000 cubic feet a day. The wells are 2,100 to 2,300 feet deep, and most of the gas is found in one sand, which is recorded in the well logs as ranging from 7 to 27 feet in thickness, with an average of about 12 feet. The producing sand is at least 600 feet below the base of the Permian and lies in the middle or upper part of the Pennsylvanian series.

The figures showing production by the Lone Star Gas Co. from this field are as follows:

	Cubic feet.
1918 (April to December, inclusive)-----	3, 192, 977, 000
1919 -----	10, 831, 193, 000
1920 (January)-----	539, 222, 000
	14, 563, 392, 000

To this should be added at least 5 per cent for the gas consumed at Lawton and Walter. Gas for field operations is furnished mainly by shallow gas wells and by oil wells that supply a little gas, so this item may be omitted from the present computation. The original average rock pressure appears to have been about 700 pounds to the square inch, though a few wells came in at a higher pressure. The average rock pressure February 1, 1920, was 240 pounds. (See fig. 6.) In view, however, of the fact that new wells now coming in show pressures of 400 to 525 pounds, the average pressure in the sand throughout the pool is evidently between these limits, and there is reason for believing that it is not far from 375 pounds. This is a little less than the mean between the highest initial pressure among recently drilled wells (525 pounds in Schwalbe well No. 2, December, 1919) and the average of all the wells at the mouth (240 pounds). Roughly, the data above recorded indicate that a little more than 50 per cent of the gas has been withdrawn from its natural reservoir. The recoverable and marketable supply remaining is therefore about 13 billion cubic feet. This must be regarded as only a very rough approximation, but it is probably not far from correct.

The problem of water encroachment and the fact that more than one company draws gas from this field add some uncertainty to the computation of the reserve supply. Competing companies in a field tend to increase the rate of depletion, owing to the fact that when one company gets a gas well the other companies that control adjoining leases are practically forced to drill or their gas will be drawn out. The principle is not essentially different from that operating in oil fields, but the effects are felt more quickly and extend over a larger area. Water troubles are already appearing in this field,

and the utmost care should be taken by the operators to guard against them.

OTHER FIELDS.

The fields above described include all that have thus far furnished gas to Dallas, Fort Worth, and other north Texas towns, with the exception of some small pools that have supplied gas to certain towns south of Dallas but are now so completely exhausted as to be negligible.

The rapid depletion of the fields in use at present is graphically illustrated by the accompanying curves of decline in rock pressure

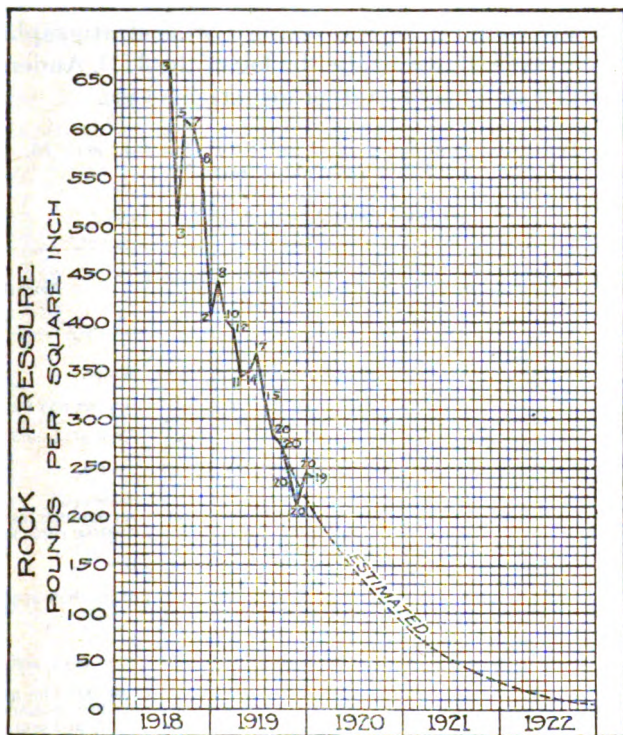


FIGURE 6.—Curve showing decline in rock pressure in the Walter gas field, Okla. Figures on curve indicate number of wells tested.

(figs. 3, 5, and 6). To counteract this exhaustion, pipe lines to other fields, described in the following pages, are being constructed as rapidly as conditions permit.

LOCO FIELD.

Special interest attaches to the Loco field at this time, as it is just being connected with the system that supplies the north Texas towns. It is a field of small area, lying almost wholly within secs. 9, 10, 15, and 16, T. 3 S., R. 5 W., near the southern edge of Stephens County,

Okla. Wegeman and Heald^a refer to it as lying along a curve of which the Healdton dome, 10 miles to the southeast, forms one extremity, and the Duncan dome, 15 miles north-northwest, forms the other. They state that this curve

appears to encircle the west end of the Arbuckle Mountains, forming, so to speak, a cross fold to the low arch which lies between the Arbuckle and Wichita uplifts. It is not meant to imply that the Healdton, Loco, and Duncan fields are situated on one long anticline. They are in fact three separate domes, but they lie in such a relation to one another as to suggest that they are more intimately connected in origin with the Arbuckle uplift than with the Wichita. The Duncan field lies north of the low arch between the two mountain uplifts, and the Loco and Healdton fields lie south of it.

Oil and gas are found in beds covering a wide stratigraphic range in the Loco field, as is illustrated by the log of the J. B. Anderson well No. 1, though this well may be rather an extreme case.

Log of J. B. Anderson well No. 1 of Lone Star Gas Co., sec. 16, T. 3 S., R. 5 W., Loco field, Okla.

[Drilled about Jan. 1, 1918.]

Formation.	Color.	Hardness.	Thickness (feet).	Depth (feet).	Remarks.
Shale.....	Red.....	Soft.....	25	25	
Sand.....	.....	do.....	20	45	Water.
Shale.....	Red.....	.....	60	105	
Sand.....	.....	do.....	12	117	Oil, gas, and water.
Shale.....	Red.....	do.....	73	190	
Sand.....	.....	.....	35	225	Show of gas and oil.
Shale.....	Red.....	.....	30	255	
Sand.....	.....	.....	16	265	Do.
Shale.....	Blue.....	.....	23	288	
Sand.....	.....	.....	17	305	Show of oil.
Shale.....	Red.....	.....	108	413	Set 12½-inch casing.
Sand.....	.....	.....	23	436	6,000,000 cubic feet of gas.
Shale.....	Red.....	.....	39	475	
Sand.....	.....	.....	20	495	Dry.
Shale.....	Blue.....	.....	23	518	
Sand.....	.....	.....	10	528	Slight show of oil.
Shale.....	Brown.....	.....	32	560	
Sand.....	.....	.....	15	575	Do.
Shale.....	Blue.....	.....	15	590	
Sand.....	.....	.....	28	618	Show of gas and water.
Shale.....	Blue.....	.....	85	703	
Sand.....	.....	.....	15	718	2,000,000 cubic feet of gas.
Shale.....	Blue.....	.....	22	740	Set 10-inch casing.
Sand.....	.....	.....	20	760	Shelly and broken.
Shale.....	.....	.....	5	765	
Lime.....	.....	.....	23	788	
Sand.....	.....	.....	12	800	Slight show of oil.
Lime.....	.....	.....	5	805	
Sand.....	.....	.....	10	815	Slight show of oil and gas.
Do.....	.....	.....	5	820	
Shale.....	Blue.....	.....	10	830	
Sand.....	.....	.....	21	851	8,000,000 cubic feet of gas.
Shale.....	Blue.....	.....	86	937	Set 6½-inch casing.
Sand.....	.....	.....	12	949	
Shale.....	Blue.....	.....	4	953	
Do.....	White.....	.....	2	955	
Do.....	Blue.....	.....	12	967	
Shell and sand.....	.....	.....	2	969	Water.
Lime.....	.....	.....	1	970	
Sand.....	.....	Hard.....	5	975	
Shale.....	Blue.....	.....	10	985	
Sand and lime.....	.....	.....	10	995	
Sand.....	.....	.....	5	1,000	Show of oil.

^a Wegemann, C. H., and Heald, K. C., The Healdton oil field, Carter County, Okla.: U. S. Geol. Survey Bull. 621, pp. 23-24, 1916.

Log of J. B. Anderson well No. 1 of Lone Star Gas Co.—Continued.

Formation.	Color.	Hardness.	Thickness (feet).	Depth (feet).	Remarks.
Shale.....	Blue.....	.....	55	1,055	
Sand and shale.....	.....	.....	7	1,062	
Slate.....	Blue.....	.....	330	1,392	
Lime shell.....	.....	.....	3	1,395	
Slate.....	Blue.....	.....	5	1,400	
Shale.....	do.....	Soft.....	65	1,465	
Lime shell.....	.....	.....	3	1,468	
Shale.....	Blue.....	.....	90	1,557	
Sand.....	.....	.....	3	1,570	
Water.....	.....	.....			

None of the producing sands in this well lie deeper than 851 feet, and throughout the field most of the producing sands are less than 1,000 feet deep. They lie in the "Red Beds," of Permian age.

The gas of this field has not been used except for drilling operations, yet since January 1, 1916, the rock pressure has decreased about

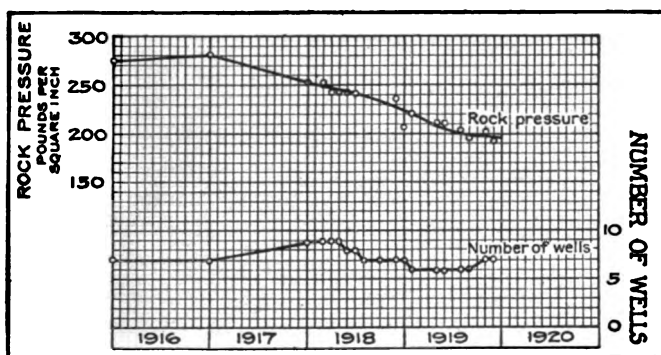


FIGURE 7.—Curve showing decline in rock pressure in the Loco gas field, Okla. In some wells tests were made in more than one sand.

90 pounds. (See fig. 7.) Reports indicate that waste in this field has been about the average, or perhaps below the average. One well, the Ida Billey No. 5, which had an initial open flow of 9 or 10 million cubic feet, blew off steadily for three weeks after the accidental opening of the gas sand by a shot of nitroglycerine. The well was drilled with a rotary drill, and the sand was penetrated without being noticed. A lower oil sand was struck, and after this was exhausted and the well abandoned the gas sand was opened by a shot set off in an effort to dislodge the casing. The well finally had to be plugged. No other important losses have occurred in this field.

The amount of gas used for drilling is roughly estimated at 7,500,000 cubic feet per well, which, for 35 wells, would be 262,500,000 cubic feet; the amount of loss due to oil wells producing from the same sand and to leakage is estimated at 200,000,000 cubic feet for the Ida Billey well and 100,000,000 cubic feet for all others, or 300,000,000 cubic feet. The original pressure in the pool was about 300 pounds

to the square inch, and the present average closed pressure of the wells is above 185 pounds. At points distant from wells the pressure, to judge by initial pressures of new wells, is probably 225 pounds. It follows that the original volume was at least 1,465,000,000 cubic feet, and the amount remaining is at least 900,000,000 cubic feet, of which perhaps 700,000,000 cubic feet may be recovered and marketed. The decline in closed pressure is shown in figure 5.

The geologic conditions afford ground for hope that this field may be extended in a direction slightly west of north and perhaps also to the southeast, though until a detailed survey is made no great reliance can be placed on this inference.

DUNCAN FIELD.

About 10 miles north of the Loco field is the Duncan field. The curve of decline in rock pressure for this field (fig. 8) indicates that

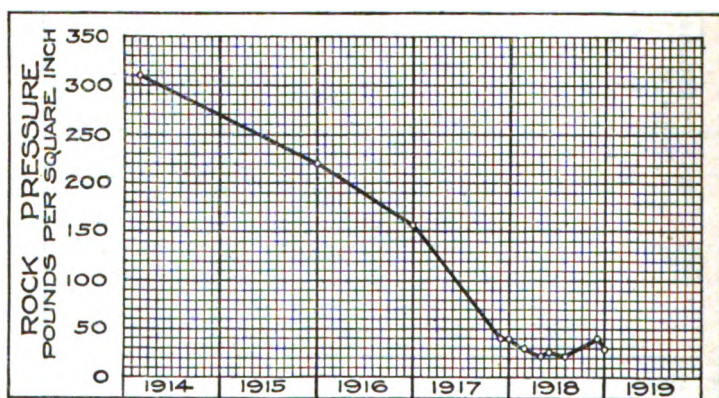


FIGURE 8.—Curve showing decline in rock pressure in the Duncan gas field, Okla.

as a prospective source of supply for north Texas cities it may be disregarded.

MINERAL WELLS FIELD.

The promising gas fields of Palo Pinto County, Tex., have not yet been drawn upon except for local use, but pipe lines are rapidly being pushed toward them, and their supply will soon be available for the north Texas cities. The Mineral Wells field lies in the east-central part of the county, near the town of Mineral Wells. Perhaps the mineralized water at this locality was related to the same set of conditions that gave rise to the oil and gas pools.

The field produces mainly from one sand in the Strawn formation, at a depth of about 1,000 or 1,100 feet. The thickness of the sand, as calculated from available well logs, ranges from 8 to 21 feet, and averages 14 feet. The producing area covers about 8 square miles. The data at hand do not show the original rock pressure, but it was prob-

ably not far from 420 pounds to the square inch. The hydrostatic head for wells 1,050 feet deep is about 450 pounds; hence this estimate may be a little low. The earliest wells of which complete records are at present available had initial rock pressures of 270 to 365 pounds. These wells were by no means the first in the field, so it must be assumed that the original rock pressure was well above that at which they came in. A porosity of 20 per cent is assumed. The total volume of gas is thus computed to be about 18 billion cubic feet. As the corrections to be made are nearly all of a plus character, arising from probable development of new territory, discovery of new sands, and the fact that the original rock pressure is conservatively estimated, it is probable that the estimate could safely be raised to 25 billions. Some of the supply has already been drawn for local use at Mineral Wells, and some has been lost through the more or less careless methods usually attending the development of a new field. Still there seems to be good reason for believing that there remains available at least 15 billion and possibly 25 billion cubic feet. Relatively this is not a large amount of gas for the area of the field, but the wells are of rather small capacity. Fifteen representative wells of this field show an average open flow of only 1,820,000 cubic feet a day.

A much deeper sand, at about 4,000 feet, having a closed pressure of about 1,400 pounds to the square inch, has been penetrated in one or two places. After the exhaustion of the shallower sand, this sand will afford a new but at present unascertainable volume of gas in reserve. It should be borne in mind that the difficulty and expense of recovering gas from a depth of 4,000 feet are considerably greater than for shallower depths.

EASTLAND FIELD.

The Eastland County field lies mostly north of the town of Eastland. The producing sands are in the Bend series, at an average depth of about 3,000 feet and extend eastward to the county line, merging into the Ranger field. This field contains much oil, and as oil production is much more profitable than gas production, it is spoken of as an oil field. Nevertheless the high rock pressure and the large open flow of the "gasser" scattered throughout the field indicate an abundant gas supply, in spite of the waste that has been involved in an overdiligent search for the more valuable oil. The gas and oil are mainly in the same sand, and sooner or later most of the gas wells, if allowed to "blow," will begin to yield oil. It was in an attempt to obtain oil that the Barker No. 1 well was allowed to blow at the rate of about 42,000,000 cubic feet a day for three months. The Railroad Commission has lately put a stop to such practices in the interest of conservation of natural gas. This waste of gas in order to obtain oil emphasizes the need of conservation, which can be

accomplished by enacting and enforcing properly drafted laws and by putting the prices of the two commodities more nearly on a parity, so that there will be as much incentive to save the one as the other.

The irregular occurrence of gas in this field makes estimation of the quantity extremely difficult. Very little gas from the field has been used commercially, but the large wastes have made a noteworthy depletion. Only the roughest sort of an estimate can be made of the amount available at present. The average open flow is about 20,000,000 cubic feet a day, and the average rock pressure is about 650 pounds to the square inch. The amount of gas originally in the field can hardly have been less than 100 or 200 billion cubic feet and of this 10 to 20 billion cubic feet has already been used or wasted.

Data regarding the wells in Eastland County are given in the following table:

Data concerning Eastland County wells.

Name and number of well.	Owner.	Depth of gas sand (feet).	Tests.			Remarks.
			Date.	Rock pressure (pounds per square inch).	Open-flow capacity (M cubic feet).	
Cooksey No. 1.....	Jackson Refining & Oil Co.	3,360	Sept. 25, 1919	900	2,809	Gas dry.
Summers No. 1....	States Oil Co.....	1,740	Sept. 23, 1919	700	50,000	Gas dry. Open flow Oct. 1, 1919, 11,640,000 cubic feet.
W. D. Sneed No. 1.	Texolean Co.....	1,920-1,927	Oct. 10, 1919	750	13,447	Well blowing open through 8-inch pipe supplying fuel for 20 rigs.
Barker No. 1.....		3,630	Oct. 17, 1919 Nov. 13, 1919 Jan. 1, 1920	1,000 42,532 34,000	42,532 47,000	Nov. 13, 1917, making 10 barrels of oil a day.
C. J. Harrell No. 1.	Mid Kansas Co...	1,920-1,960	Oct. 16, 1919	750	47,000	Mudding in gas to drill deeper.
Thraves et al. No. 1.	Texas Co.....	1,785-1,790		800	40,000	Nov. 1, 1919, open flow, 26,000,000 cubic feet.
Harrell No. 1.....	Ranger.....			900	100,000	
Miller No. 2.....	Mother Pool Oil Co.			250	700?	Aug. 30, 1919, was making 10,000,000 cubic feet of gas; shut in September, 1919.
Beard No. 1.....	Folsom Oil Co....	1,700		650	8,000	
Kincaid No. 1.....	Ardizzone-Bradley	1,768-1,761		300	6,000	Sept. 6, 1919, drilled to 3,220 feet; 20 barrels of oil.
C. J. Harrell.....	Ranger-Texas....	1,730-1,733	Nov. 1, 1919 Nov. 21, 1919	800	17,000	Jan. 28, 1920, well leaking gas badly. Nov. 21, 1919, struck gas at 1,725 feet; drilled 6 inches into the sand.
Harmony Church Lot No. 1.	Mildren Oil & Gas Co.	1,720-1,781?	Nov. 24, 1919 Dec. 2, 1919		39,288 26,000	Feb. 3, 1920, fixing to mud-in to drill deeper.
Jim Harrell.....	States Corporation.	1,762-1,774	Jan. 1, 1920		12,852	Gas slightly wet.
J. C. Harrell.....	do.....		Dec. 10, 1919 Dec. 20, 1919 Jan. 1, 1920 Feb. 3, 1920	35,408 34,489 31,076 510	25,000	Gas dry. Slightly wet; making little salt water.

* Estimated.

Data concerning Eastland County wells—Continued.

Name and number of well.	Owner.	Depth of gas sand (feet).	Tests.			Remarks.
			Date.	Rock pressure (pounds per square inch).	Open-flow capacity (Mcubic feet).	
O. E. Meador No. 1	Mid-Kansas Co.	3,095-3,110	Oct. 16, 1919	38	850	Using this gas for boiler fuel.
Bowles No. 1.			Sept. 5, 1919	550	* 20,000	25 drilling wells using gas; makes considerable gasoline in drips.
Hogg No. 5.	Sinclair Oil & Gas Co.		Sept. 5, 1919	500	880	15 drilling rigs using gas.
Crowell No. 1.		2,610-2,621	do.....	* 150	974	
Crowell No. 2.		2,602-2,610	do.....	140	2,304	Slightly wet.
Cypert No. 1.		2,485	Oct. 3, 1919	405	19,419	Shows little water; no oil.
Cypert.			Dec. 5, 1919	255	13,000	
Vaught No. 1.	Atlantic Petroleum Co.	2,492-2,500	Sept. 3, 1919	460	2,735	Sprays gasoline, water, and oil when blowing; supplies gas to 10 drilling rigs. Later record, Feb. 23, 1920, gives sand at 2,490-2,497 feet, total depth 2,532 feet, 20,000,000 cubic feet of gas; probably drilled deeper.
Vaught No. 2.		2,582-2,588	Feb. 23, 1920		* 25,000	75 barrels of oil; total depth 2,600 feet.
Emde No. 1.	Plains Oil & Gas Co.	2,570-2,577	Sept. 4, 1919	500	5,443	20 drilling rigs.
Foot No. 2.	Magnolia Petroleum Co.	2,922-2,927	Sept. 5, 1919	950	20,000	
W. B. Lewis No. 1.	Burmesal Co.	2,780-2,783	Dec. 3, 1919		11,000	Not completed.
Shellenberger No. 1	Southern California Drilling Co.				877	Total depth 2,700 feet; Dec. 3, 1919, fishing for tools.
Shellenberger No. 2	do.....	2,833-2,838	Nov. 12, 1919	450	19,000	
Shellenberger No. 1	Osceola Drilling Co.	3,048, 3,060	Dec. 3, 1919		1,042	Total depth, 2,850 feet.
Breistford No. 1.	Prairie Oil & Gas Co.	3,048, 3,060	Feb. 13, 1920	860	12,250	Gas dry; leaking badly.
Shorter White No. 1.	Quaklin Petroleum Co.		Dec. 22, 1919		4,186	Not complete; fishing for tools.
B. A. Davis No. 1.	Vulcan Oil Co.		Feb. 13, 1920		13,678	Making a little oil; blowing through trumble trap.
Rickard No. 1.	Texas Co.		do.....	500	5,253	Gas leaking around casing.
Rickard No. 2.	do.....	3,535-3,542	Nov. 25, 1919		31,000	Total depth, 3,542 feet; making 100 barrels of oil.
A. L. Duffer No. 1.	do.....		Nov. 8, 1919	145	* 8,000	
A. L. Duffer No. 2.	do.....				10,000	Total depth, 3,695 feet.
A. L. Duffer No. 6.	do.....		Nov. 8, 1919	480	* 14,000	Total depth, 3,220 feet.
Patton No. 1.	Humble Oil & Refining Co.		Jan. 3, 1920	200	378	Spraying oil.
L. A. Hightower No. 1.	Texas Co.		Nov. 8, 1919	408	* 3,000	Total depth, 3,606 feet.
Dountain No. 1.	J. M. Sullivan Drilling Co.		Jan. 8, 1920	595	6,500	Gas dry; packing blew out trying to shut in well.
Scott No. 1.	Humble Oil & Refining Co.		Jan. 3, 1920		5,213	
Schoor No. 1.	do.....	3,122-3,148	Dec. 31, 1919	850	2,522	Gas wet; total depth 3,791 feet; plugged back to 3,300 feet.

* Estimated.

RANGER FIELD.

No sharp line of demarkation exists between the Eastland and Ranger fields. Each produces oil and some gas, the Ranger field mostly casing-head gas. Immediately west and southwest of the town of Ranger are two small groups of wells whose capacities are given in the following table:

Wells near Ranger.

	Rock pressure (pounds per square inch).	Open-flow capacity (cubic feet per day).
Duffer No. 1.....	145	8,000,000
Duffer No. 2.....	.....	10,000,000
Duffer No. 5.....	110	20,000,000
Duffer No. 6.....	480	14,000,000
Patton No. 1.....	200	378,000
Patton No. 5.....	325	1,533,000

These wells do not promise a large ultimate output. If there were a pipe line near by, and if their pressure were somewhat higher, so that they would feed into the line, they would add perceptibly to the supplies of the region.

MINOR FIELDS.

The Mexia-Groesbeck field of Limestone County was not regarded by G. C. Matson ⁴ as of great promise and has followed the predictions of decline very closely. It may be disregarded, as it has practically reached the point of exhaustion.

The northern Louisiana fields are only about 160 miles from Dallas and are not beyond consideration so far as distance is concerned, but their available supply of gas is insufficient to warrant the expense of a line into north Texas. They produce little surplus above the demands of the markets they already supply.

West of Dallas and Fort Worth there are small scattered pools, none of which would justify a pipe line, but which are of interest owing to the encouragement they offer in the search for larger pools.

The Desdemona field, at the junction of Eastland, Comanche, and Erath counties, contains 14 or 15 gas wells of moderate capacity. A pipe line has been surveyed from this field to Stephenville and Dublin, both in Erath County. A few months ago this field was regarded by both oil and gas men as one of great promise, but the production of its wells has fallen off rapidly.

⁴ Ehaw, E. W., Matson, G. C., and Wegemann, C. H., Natural-gas resources of parts of north Texas: U. S. Geol. Survey Bull. 629, pp. 87-110, 1918.

A well yielding 50,000,000 cubic feet of gas daily has recently been completed in Erath County, just north of Exray, about 16 miles from the Desdemona field and but little farther from the Ranger and Mineral Wells fields. It is close to the nonproductive belt across Erath, Comanche, and Brown counties indicated by geologic conditions and dry holes.

Stephens County does not at present afford evidence of much gas though it includes good oil territory, and the oil contains a considerable proportion of gas. It is not unlikely that here, as in Eastland County, just to the south, there may be developed some gas wells interspersed among oil wells. Some of the Eastland gas wells are very near the Stephens County line.

Shackelford and Callahan counties supply enough gas for the use of local towns but do not promise at present a supply for transmission to other points, though considerable portions of these counties have not been tested and it is quite possible that they may have one or more valuable gas pools. Coleman County contains the Jim Ned field, and Brown County the Bangs field. These fields also are sufficient only for local use.

The only other developed gas pool west or northwest of Dallas is the Amarillo field, a few miles north of Amarillo. This field is reported to contain one of the largest wells on record, a well with a daily capacity of 107,000,000 cubic feet. Six wells in the field have a total open flow reported as 171,000,000 cubic feet. This field can not be regarded as an immediate source of relief to Dallas if indeed it can be regarded as available at any time. It is 270 miles northwest of the western extremity of the 18-inch pipe line that extends westward from Dallas and is 210 miles from Walter, Okla. There are probably no engineering difficulties in the way of laying a connecting line, but it is somewhat doubtful if a sufficiently large yield could be developed to warrant the great expense of piping the gas to Dallas and other north Texas cities.

PROSPECTIVE TERRITORY.

In the report on the gas investigation of 1915,⁵ it was pointed out that the country extending 150 miles north and northwest of Dallas and Fort Worth offered great encouragement to the oil and gas prospector. Developments since that time have shown the correctness of this suggestion, and it may be safely assumed that there are still several undiscovered gas pools in this region. The reasons for this assumption are much the same as those stated in the earlier report, as quoted below. Testing has not yet been sufficiently thorough to show that all the pools of the region have been discovered.

⁵ U. S. Geol. Survey Bull. 629, pp. 62-65, 1916.

Geological indications.—The geology of the region extending north and west of Dallas and Fort Worth for 150 miles is, as already stated, generally favorable to the origin, accumulation, and preservation of gas and oil pools. All considerations, both practical and theoretical, point to the existence of undiscovered pools both of gas and of oil in the region. The favorable geologic conditions may be summarized as follows:

1. The rocks of the region belong to the Carboniferous and Cretaceous systems, which contain much gas and oil in other regions. Such rocks as the pre-Cambrian, which nowhere contain valuable pools of gas or oil, are not found or lie so far below the surface that they may be left out of consideration.

2. The general structure is favorable. The layers of rock have the form of a broad, shallow basin or geosyncline, and most of the gas and oil of the world occur in such general basins. The rocks lie nearly flat and at some places, particularly between Fort Worth and Red River, have a broad terrace form.

3. The details of structure are locally favorable. Though the beds lie nearly flat, their general attitude is at many places modified by irregularities of various kinds, and here and there they are undoubtedly arched up into well-developed domes and anticlines, as has been shown by observations made in similar basins elsewhere and by the conditions existing in those parts of this basin that have been tested.

4. The chemical composition of the rocks shows that they may have been the source of large quantities of oil and gas. Carbonaceous sediments, including coal, though not so abundant as in some other regions, are very common.

5. The physical nature of the rocks also shows that they are well suited to accumulate and retain gas and oil pools. They include many layers of open-textured sand of various degrees of porosity, in more or less lenticular beds. These sands make up less than half of the rock, a fact favorable to their retention of pools of oil and gas, because it makes the washing out of the beds with fresh water difficult or impossible.

6. The history of the rocks has been favorable to the accumulation and retention of pools. With the exception of those underlying Dallas, they have apparently not been tilted back and forth until all the fluids in the sands have migrated elsewhere. Salt water, which is taken as an indication of slight or no underground circulation, is found almost throughout the region, and it may be fossil sea water which has not shifted far since the beds were deposited.

7. The rocks have been under sufficient pressure to induce the degree of metamorphism required to separate the hydrocarbons that make up gas and oil but have not been so much compressed as to drive these fluids out of the region and leave nothing but carbonized remains. David White, in discussing this subject recently, has pointed out that the quality of gas and oil found in any rocks shows a relation to the stresses to which the rocks have been subjected and has suggested that gas pools are likely to be most numerous on the sides of an oil region that lie nearest to regions that have undergone greater stresses. According to this principle, gas pools should be most numerous on the east side of this oil and gas region.

The discovery of new pools may undoubtedly be hastened by careful studies of the rocks, made to determine the most promising places for drilling. Without such assistance in finding pools, the cities of Fort Worth and Dallas will probably fail to obtain abundant supplies of natural gas unless they draw supplies from Oklahoma or other distant fields. As the country is developed, and as the oil and gas resources become gradually exhausted, wildcat wells will no doubt increase in number and greater care will be taken to drill in the most favorable places. The search for gas and oil pools should begin with domes

and anticlines, for they are by far most likely to contain such pools. Later explorations should extend to structures less favorable, and finally to regions in which the underground structure can not be determined because significant outcrops are poor or are lacking.

Inferences based on experience and on the doctrine of chances.—The proportion of wildcat wells that have been successful in the region under discussion indicates that if it were practicable to make tests of each square mile, a good many more gas pools would be found. Such a series of tests is, of course, as yet out of the question, but illuminating inferences may be drawn from the results of the somewhat random wildcatting and the proportion of successful wells. The importance of these tests becomes more obvious when we apply to them the law of probabilities and remember the fact that some counties, especially Parker, have had scarcely one deep test. If a township were known to contain a pool of oil a mile across, the chances of finding that pool by a random well would, of course, be 1 in 36. If a county covering 1,000 square miles contains one pool 3 or 4 miles across or having an area of 10 square miles, the chances of finding the pool by a random test are 1 in 100. Other considerations, of course, may enter into the problem, such as the fact that the well must be sufficiently deep and drilled with sufficient care to make an adequate test; nevertheless a single unsuccessful wildcat well drilled at random does not throw a great deal of light on the existence of gas and oil pools in a considerable area.

Later developments and surveys have brought to light additional facts concerning the stratigraphy and structure of the region, but many details are not yet known and can not be learned except by detailed and expensive surveys and long and careful study. Plate VIII shows some of the known or probable structural features of the region. Prospecting guided by additional surveys may open up several gas pools. Many tests have already been made in some of the promising areas, and their results should be carefully studied in connection with the results of detailed surveys, to obtain a more intimate knowledge of the formations and their attitude.

The cross folding between the Wichita and Arbuckle mountains of southern Oklahoma, as referred to by Wegemann and Heald, has already been mentioned. The geographic relation between the Wheeler and Fox fields suggests another fold parallel to the one just mentioned. Wegemann and Heald⁶ speak of an anticline on the east bank of Red River 30 miles west and 8 miles south from the Healdton dome, in alinement with the Devol anticline of the Grandfield district.

Stephenson⁷ has described the Preston anticline and the Leonard-Celeste monocline, extending from Marshall County, Okla., south-eastward into Hunt County, Tex. The Preston anticline has produced some oil and gas. It is not known by the writers that any deep wells have been drilled near the axis of the Leonard-Celeste monocline "nose."

⁶ U. S. Geol. Survey Bull. 621, p. 24, 1916.

⁷ Stephenson, L. W., A contribution to the geology of northeastern Texas and southern Oklahoma: U. S. Geol. Survey Prof. Paper 120, p. 129, 1919.

The outline and structure of the Bend arch^{*} are now fairly well known, but prospecting has proceeded more rapidly on the eastern flank than on the western. The Bangs and Eastland fields lie very nearly on the axis. Pools of small extent may still be found on or near the axis, and possibly on smaller structural irregularities east or west of the axis.

The Marathon fold, which is described by Beede and Liddle^{*} as possibly extending from Brewster County northeastward into Foard County (see Pl. VIII), may prove favorable for the accumulation of oil and gas and doubtless will receive careful attention throughout its length.

CONCLUSIONS.

A summary of the available contents of the fields that are either in use at the present time as sources of supply for the north Texas towns, or presumably available for connection before the winter of 1920-21, is given below. The figures indicate estimated recoverable reserves of natural gas January 1, 1920.

	Cubic feet.
Petrolia field (including Martin wells)-----	10, 090, 000, 000
Fox field-----	4, 000, 000, 000
Walter field-----	13, 000, 000, 000
Loco field-----	700, 000, 000
Mineral Wells field-----	23, 000, 000, 000
Eastland and Ranger fields-----	150, 000, 000, 000
	200, 700, 000, 000

As shown by the curve of gross production of the Lone Star Gas Co. (fig. 9), the demand for 1920 may be estimated at 23,500,000,000 cubic feet. For 1921, a somewhat slower rate of increase being assumed, it may be 25,000,000,000 cubic feet. Predictions of this sort should not be carried too far into the future, owing to constant changes in conditions. If the necessary wells were drilled, pipe lines and compressors installed, and if the demand remained uniform at the estimated figure for 1920, the estimated supply of gas, 200,700,000,000 cubic feet, would last about 8½ years. There would be shortages in the winter due to the greater demand at that season. Figure 10 shows the seasonal variations in sales during 1919.

The present industrial consumption of gas in Dallas amounts to more than 50 per cent of the total amount of gas delivered. Any decrease in the volume used in this manner would of course increase the

^{*} Hager, Dorsey, Am. Inst. Min. Eng. Bull. 138, p. 1109, 1918.

^{*} Beede, J. W., Further notes on the structure near Robert Lee, Coke County, Tex.: Texas Univ. Bull. 1847, pp. 3-7 [1920].

Liddle, B. A., The Marathon fold and its influence on petroleum accumulation: Idem, pp. 9-16.

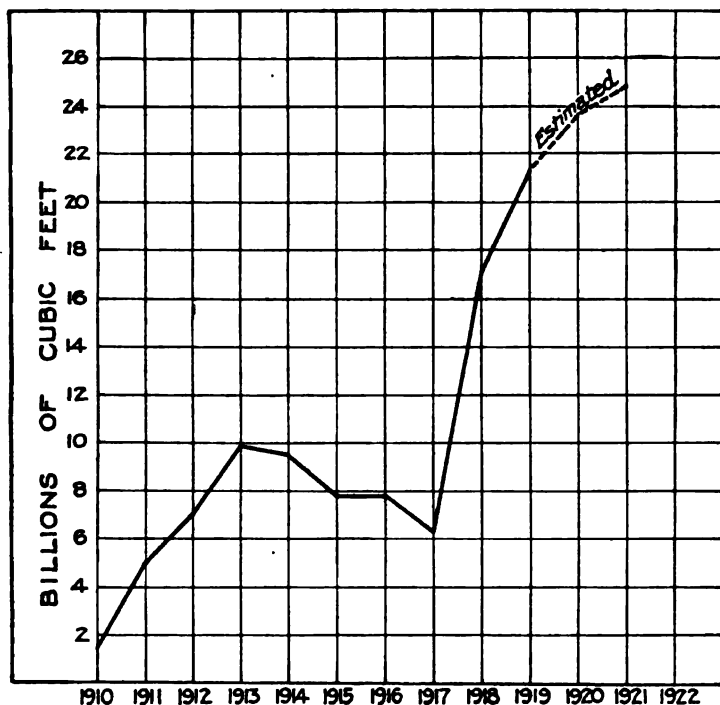


FIGURE 9.—Curve showing production of gas by Lone Star Gas Co., 1910-1919, and estimated production for 1920-21.

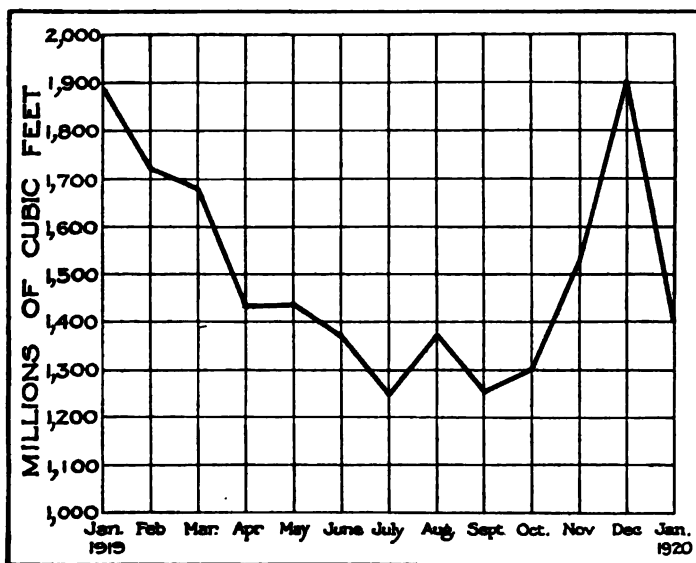


FIGURE 10.—Curve showing monthly sales of gas by Lone Star Gas Co., January, 1919, to January, 1920.

length of time that the remaining supply would last. The total leakage is 20 to 25 per cent. It is questionable whether this loss can be reduced materially under present conditions. The expense of repairs is often far above the value of the product wasted, and gas companies are loath to conserve the gas if conservation is of no economic advantage to themselves.

The curve in figure 10 is flattened out by the increased industrial consumption during the summer. Although the decrease of industrial consumption, if not its entire elimination, is regarded as an important step in the conservation of natural gas, it is only fair to point out the fact that the summer sales to industrial users have

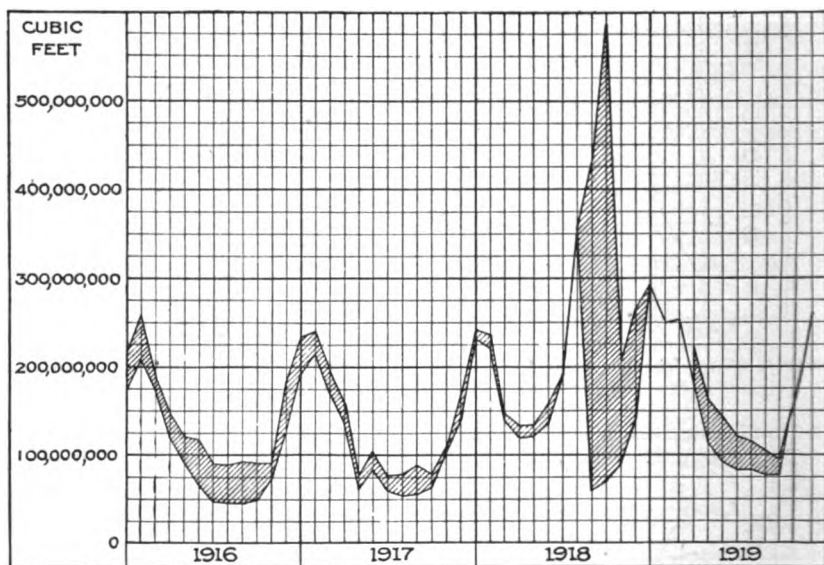


FIGURE 11.—Curves showing domestic and industrial consumption of gas at Fort Worth, Tex. Shaded areas indicates industrial consumption.

enabled many gas companies to maintain a level of production throughout the year that was necessary in order for them to fulfill their contracts with well owners. The usual form of such a contract provides that the output of a well must never fall below a certain daily minimum. Owing to the extreme seasonal fluctuation of domestic consumption, the specified minimum would in the summer often not be attained if the company were supplying domestic consumers only. A curve showing domestic and industrial consumption at Fort Worth (fig. 11) is appended for comparison.

It seems probable that with rigid economy and scientific conservation the present available supply of natural gas in the region around Dallas may be depended on to suffice for six to ten years, though there

will be shortages nearly every winter. Little can be certainly predicted for future developments until natural gas is elevated to an economic position side by side with its associate, petroleum, and frank recognition is given to the peculiar hazards of the gas industry. Natural gas to-day, owing to the low value placed upon it, is essentially in the position of being a by-product of the petroleum industry. This condition is neither in the interest of the gas consumers nor a stimulus to the conservation of this valuable natural product.



DEPARTMENT OF THE INTERIOR

JOHN BARTON PAYNE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

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**THE LANCE CREEK OIL AND GAS FIELD
NIOBRARA COUNTY, WYOMING**

BY

E. T. HANCOCK

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THE LANCE CREEK OIL AND GAS FIELD, NIOBRARA COUNTY, WYOMING.

By E. T. HANCOCK.

INTRODUCTION.

The Lance Creek oil and gas field is situated in Niobrara County, east-central Wyoming, about 25 miles from the east line of the State. The center of greatest activity is about 45 miles southwest of Edgemont, 80 miles northeast of the Big Muddy field, and 85 miles east and a little south of the Salt Creek field. The Lance Creek field can be reached either from Edgemont, on the Chicago, Burlington & Quincy Railroad, or from Lusk or Manville, on the Chicago & Northwestern Railway. The east end of the field, as shown on the geologic map (Pl. X), is about 22 miles due north of Lusk, and the west end is about the same distance north of Manville.

HISTORY OF DEVELOPMENT.

According to notes submitted to the writer by Dr. J. E. Hawthorne, of Lusk, the early history of development in the Lance Creek field is briefly as follows:

As early as 1912 Dr. Hawthorne made an effort, by advertising, to obtain the necessary funds to drill a hole on Buck Creek. He failed to interest anyone at that time, but on April 29, 1913, what is known as the Lusk, Wyoming, Oil Co. was incorporated. After consulting L. W. Trumbull, State geologist, the company decided to drill a hole in the extreme northeast corner of sec. 15, T. 35 N., R. 64 W. Drilling was begun in August, and by June, 1914, when the funds were exhausted, a depth of 2,250 feet had been reached. A California company, represented by H. A. Rispin, then attempted to finish the hole but did not drill deeper than 2,600 feet.

In April, 1913, Mr. McWhinnie, of Douglas, shipped a portable rig to Lusk. The rig was taken out to the SE. $\frac{1}{4}$ sec. 31, T. 36 N., R. 64 W., early in June, and on July 12 the drill had reached a depth of 268 feet. Later drilling was continued to 1,200 feet, and the hole was then abandoned.

In the summer of 1914 Edwin Hall organized the Pine Dome Oil Co., composed of Salt Lake mining men. A standard rig was procured, and drilling was begun in the N. $\frac{1}{4}$ sec. 33, T. 36 N., R. 65 W.

Owing to the development of a crooked hole at a depth of 1,700 feet. this company also abandoned the field.

The Montana-Wyoming Oil Co. of California, represented by H. A. Rispin, started a well in the SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 3, T. 35 N., R. 65 W., about the 1st of November, 1916. This company drilled about 200 feet and then abandoned the work until the following year. The well was finally finished in 1919 by the Western States Oil Co., which brought in a water well.

In 1916 Dr. Hawthorne procured from the State a lease on sec. 36, T. 36 N., R. 65 W., and subleased it for a period of seven months to the California company represented by Mr. Rispin. The lease was subsequently extended for five months. Later Dr. Hawthorne obtained another lease from the State and subleased the tract to the Ohio Oil Co. This company erected a standard rig and commenced drilling on September 27, 1917. The drill penetrated the first oil sand at a depth of 2,689 feet on March 13, 1918. This sand yielded 80 barrels of oil during the first 24 hours. The company resumed drilling April 29, 1918, and reached the principal oil sand October 6, 1918. When the drill had penetrated the sand to a depth of 2 feet 6 inches the well flowed at the rate of about 1,500 barrels during the first 24 hours. Since that date a number of other wells have been drilled in the principal oil sand, with results set forth on pages 117-120.

ACKNOWLEDGMENTS.

In presenting this report the writer desires to express his thanks to David White for valuable suggestions and criticisms and to Robert M. Campbell for assistance in the field. He feels particularly indebted to Mr. R. F. Gray, county surveyor of Niobrara County, for information relative to section and quarter corners. He also wishes to thank the oil and gas operators for their willing cooperation in furnishing the records of deep borings. Finally, he wishes to express his appreciation for the many acts of courtesy by the citizens of Lusk and vicinity.

PURPOSE OF THE PRESENT INVESTIGATION.

The principal object of the investigation was to procure all the information obtainable relating to the composition and structure of the sedimentary beds and the conditions controlling the accumulation of oil and gas, and to arrange that information in such form as to promote the economic development of the field. To attain that object it was necessary to trace out and locate the beds on the surface and to determine their dip or degree of inclination at close intervals.

FIELD WORK.

The field investigation that furnished the basis for the present report was carried on between September 11 and November 5, 1918. The field observations were made and the maps prepared under the supervision of the writer. In the process of mapping nearly all the locations were made by triangulation, and the elevations were determined by means of vertical angles. The instrument used was the ordinary 15-inch plane table and telescopic alidade. Two base lines were carefully measured by means of a steel tape, one in the valley of Lance Creek and the other near the east end of the field. After the plane table had been carefully oriented at the extremities of the base lines, the derricks and a number of previously constructed monuments were located by intersection. A certain elevation was assumed for the instrument at the south end of the base line on Lance Creek, and the elevation of each subsequently located point was determined from this assumed elevation. Later these elevations were adjusted to conform to the correct elevation of the top of the casing of the Ohio No. 1 or discovery well, as determined by the Illinois Pipe Line Co. In the process of mapping many of the land corners were located either by intersection or through the use of the stadia, after the instrument had been carefully located by triangulation. The section lines were then drawn to conform as nearly as possible to the located corners and to the data shown on the official township plats.

SURFACE FEATURES.

CHARACTER OF SURFACE AS RELATED TO FUTURE DEVELOPMENT.

Most of the development work that is being carried on in the Lance Creek field is confined to the relatively low-lying tract between the more or less continuous ridge of the Fox Hills sandstone on the north and the escarpment formed by the White River beds on the south. The two principal points of supply are Lusk and Manville, on the Chicago & Northwestern Railway. The oil companies and Niobrara County have, at considerable expense, laid out and constructed an excellent graded road the entire distance from Lusk to the productive portion of the field, where the main camps of the Ohio, Buck Creek, and Midwest oil companies are located. A short distance south of the field is a secondary road that extends from the principal highway in a northwesterly direction over the ridge underlain by the White River beds and down to the valley of Lance Creek.

An excellent road has also been laid out from Manville to the oil field, and construction work is well underway. This road, which is to take the place of the one previously used, will furnish a direct

route from the Chicago & Northwestern Railway to the west end of the field.

Trails lead from the principal highways to the different parts of the field. These have received very little attention, but in general the streams have not cut their channels very deeply, and therefore it is not a difficult matter to reach most any part of the field even with heavily loaded trucks.

DRAINAGE.

There are no perennial streams in the Lance Creek field. Even Lance Creek, which has a well-defined channel, is dry the greater part of the year. The long gullies in the western part of the field either lead down to the valley of Lance Creek or to Little Lightning Creek, its tributary from the west. The gullies that open into Lance Creek from the east all head near the top of a divide which separates the drainage system of the western part of the field from that of the eastern part. The run-off from the east slope of the divide either empties into Young Woman Creek or finds its way into Buck Creek. Whichever course it takes, it finally reaches Lance Creek, for Buck Creek joins Lance Creek about 7 miles north of the field, and the drainage into Young Woman Creek reaches Lance Creek about 6 miles farther down its course. Although the principal streams in the Lance Creek field are without running water most of the year, there is sufficient seepage so that the deeper portions of their beds generally contain standing water, and even where the bed is entirely dry water can be obtained by drilling to a very slight depth.

STRATIGRAPHY.

GENERAL FEATURES.

The oldest beds exposed in the Lance Creek field lie about 1,650 feet below the top of the Pierre shale of the Montana group and are exhibited at the crest of the anticline in the western part of the field. In the Powder River dome,¹ which lies about 15 miles west of Salt Creek, oil seeps are found in the Sundance, Morrison, and Dakota (?) (Cloverly) formations and in the Mowry shale member of the Benton shale, as shown in the columnar section of the Powder River field on Plate XI. In a discussion of the strata of the Lance Creek field in relation to oil accumulation it is therefore necessary to consider the formations at least as low as the Jurassic. The nature of the beds between those that crop out and the oil and gas bearing sand is well shown in the log of the discovery well on page 113. The composition of the underlying formations can only be inferred through comparison with other localities.

¹ Wegemann, C. H., The Powder River oil field, Wyo.: U. S. Geol. Survey Bull. 471, pp. 56-75, 1912.

The following section, which is believed to represent the stratigraphy in the Lance Creek field as low as the base of the Sundance formation, was made up from data collected in the Upton-Thornton field, 80 miles to the north, and from the records of borings at Cambria.² The section from the top of the Dakota to the bottom of the second fire clay in the Morrison is taken from the log of the bore hole of the Antelope mine. The part of the section comprising the lower portion of the Morrison formation and the Sundance formation is taken from the log of the deep well at Cambria.

Rock formations in the Lance Creek field, Wyo.

System.	Series.	Group.	Formation and member.	Character.	Thickness (feet).
Quaternary.	Recent.		Alluvium.	Sands and loams with some admixture of coarse material.	Variable.
Tertiary.	Oligocene.		White River formation.	Very soft unconsolidated greenish-gray to white sand, interbedded with reddish to grayish clay shale. Commonly overlain by greenish-gray, very coarse grained sandstone, in places coarsely conglomeratic.	Variable.
Tertiary (?).	Eocene (?).		Lance formation.	Sandstone and sandy shale, with thin beds of coal.	Only the lower beds were examined.
Cretaceous.	Upper Cretaceous.	Montana.	Fox Hills sandstone.	Sandstones with some sandy shales. Some of the sandstones, especially those near the top, include numerous large reddish-brown concretions, many of which are very fossiliferous.	500
				Dark-gray shales interbedded with thin beds of hard sandstone and thicker beds of soft sandy shale.	700
				Dark-gray shale, including thin beds of sandy shale and beds of fossiliferous calcareous concretions.	600
			Pierre shale.	Shannon(?) sandstone member, coarse-grained greenish-gray sandstone with many yellowish-brown iron-stained concretions.	16-50
				Predominantly dark-gray shale, but including lenticular masses and some very thin beds of fossiliferous calcareous concretions.	1,950
		Colorado.	Niobrara formation.	Soft shaly limestone or impure chalk, including some clay and sand.	200

² Darton, N. H., U. S. Geol. Survey Geol. Atlas, Newcastle folio (No. 107), p. 4, fig. 5, 1894.

Rock formations in the Lance Creek field, Wyo.—Continued.

System.	Series.	Group.	Formation and member.	Character.	Thickness (feet).
Cretaceous.	Upper Cretaceous.	Colorado.	Carlile shale.	Dark shale with thin beds of soft sandstones (Wall Creek sandstone member) near the base.	700
			Greenhorn limestone.	Impure limestone.	50
			Graneros shale.	Dark-gray to black shale including many large calcareous concretions, especially in the upper part.	575
				Mowry shale member.	100
				Dark sandy shale grading upward into typical Mowry shale.	25
				Newcastle sandstone member.	3-50
				Dark-gray to black shale.	175
			Dakota sandstone.	Thin-bedded to massive hard buff sandstone.	60*
	Lower Cretaceous.		Fuson formation.	Shale and thin-bedded sandstone.	20
			Lakota sandstone.	Sandstone, in part conglomeratic, with some coal beds near the base.	190
Cretaceous (?).	(?)		Morrison formation.	Light-gray to pinkish shale.	130
Jurassic.	Upper Jurassic.		Sundance formation.	Light-gray to dark greenish-gray and pinkish sandy shale with a 25-foot sandstone near the base.	346

UNEXPOSED ROCKS.**JURASSIC SYSTEM.****SUNDANCE FORMATION.**

The Sundance formation is exposed at many places in the Black Hills and at certain other localities in eastern Wyoming—for example, in the Powder River field, west of the Lance Creek field, and in the vicinity of Hartville, on the south. By comparing the formation in these different localities it is possible to form a reasonably accurate notion of its composition in the Lance Creek field. As an aid in

making such a comparison the reader is referred to the columnar sections on Plate XI.

At Cambria the Sundance formation is composed essentially of light-gray and pinkish shale, with one 25-foot buff sandstone near the base. Farther southeast, in the Edgemont quadrangle,³ the formation contains a much larger proportion of sandstone and is overlain by a fine-grained massive cliff-forming sandstone, known as the Unkpapa sandstone, whose maximum thickness is 225 feet. The greatest development of this sandstone in the Black Hills region is in the hogback east of Hot Springs and Cascade Springs, and it gradually decreases in thickness toward the west.

The Sundance formation as exposed near North Platte River, about 13 miles northwest of Hartville, Wyo., is reported⁴ to be about 200 feet thick. The lower part consists of about 140 feet of buff to nearly white sandstone, and the upper 60 feet includes a variable amount of more or less slabby sandstone with interbedded clays. The formation is exposed in the Powder River field,⁵ in sec. 33, T. 41 N., R. 81 W., along the bed of a canyon that enters Salt Canyon from the north. Here about 10 or 15 feet of the formation is brought to the surface by a sharp minor fold. The exposure consists of argillaceous limestone beds a foot or two in thickness which yield abundant fossils and, interbedded with the limestone layers, numerous beds of dark-gray shale.

CRETACEOUS (?) SYSTEM.

MORRISON FORMATION.

The Morrison formation, which is doubtfully referred to the Cretaceous system, overlies the Sundance conformably. It represents fresh-water conditions of sedimentation, whereas the Sundance represents marine conditions.

The section of a drill hole at the Antelope mine at Cambria⁶ (see columnar section for Upton-Thornton field, Pl. XI) shows two beds of fire clay, one 3 feet and the other 7 feet thick, separated by sandstone. The deep well at Cambria⁷ was begun just below the 7-foot bed of fire clay and penetrated 130 feet of light-gray to pinkish shale, also included in the Morrison formation.

According to the description of the formation given by Darton and Smith,⁸ it is 100 feet thick west of Minnekahta, S. Dak., but farther east it thins out and disappears. For the Edgemont quad-

³ Darton, N. H., and Smith, W. S. T., U. S. Geol. Survey Geol. Atlas, Edgemont folio (No. 108), p. 4, 1904.

⁴ Smith, W. S. T., U. S. Geol. Survey Geol. Atlas, Hartville folio (No. 91), p. 3, 1903.

⁵ Wegemann, C. H., The Powder River oil field, Wyo.: U. S. Geol. Survey Bull. 471, p. 61, 1912.

⁶ Darton, N. H., U. S. Geol. Survey Geol. Atlas, Newcastle folio (No. 107), p. 4, 1904.

⁷ Idem, p. 8.

⁸ Darton, N. H., and Smith, W. S. T., U. S. Geol. Survey Geol. Atlas, Edgemont folio (No. 108), p. 4, 1904.

range as a whole it may be said that the formation ranges in thickness from practically nothing to 125 feet and consists of grayish, greenish, and maroon massive shale, including thin beds of fine-grained white sandstone. Like the underlying Sundance formation, the Morrison is exposed along North Platte River about 13 miles northwest of Hartville,⁹ and in that locality it contains about 100 feet of massive shales or hardened clays of various colors—green, purplish, reddish, light and dark gray to nearly black—with one or more thin beds of moderately hard, compact light-grayish limestones.

In the Powder River field, according to Wegemann,¹⁰ the formation is about 250 feet thick and consists of shale with a few hard sandstone beds from 3 to 8 feet thick. The shale in the lower part of the formation has a greenish tinge, but that in the upper part is maroon.

CRETACEOUS SYSTEM.

LOWER CRETACEOUS SERIES.

The Morrison formation of northeastern Wyoming is commonly overlain by a rather massive sandstone. In the Powder River field, according to Wegemann,¹¹ it is overlain by a coarse conglomeratic sandstone 56 feet in thickness with a thin bed of coal at its base. In that field the sandstone is a lithologic unit, but 25 miles to the north, where it crops out along the Big Horn uplift, it consists of numerous thin layers of sandstone with interbedded shale. In the report on the Powder River oil field this sandstone was doubtfully referred by Wegemann to the Dakota sandstone. In his second report on the Salt Creek oil field,¹² however, the same beds are included in the Lower Cretaceous series under the name Cloverly formation, mainly on the evidence of fossil plants which were collected from layers of shale that lay between beds of conglomerate near the base. These fossils were identified by F. H. Knowlton as undoubtedly Kootenai species, and hence there is little doubt that the conglomerate is equivalent in age to at least part of the Kootenai¹³ of Montana. Overlying the conglomerate is 80 feet of dark, unfossiliferous shale, above which is a 14-foot bed of shaly sandstone whose top layers are strongly ripple marked. According to Wegemann, this bed, though comparatively thin, is found at many places throughout this region and appears to be of wide extent, and accordingly he suggests that if the formations of the Black Hills are all present in the Salt Creek field, the 14-foot sandstone may represent

⁹ Smith, W. S. T., U. S. Geol. Survey Geol. Atlas, Hartville folio (No. 91), p. 3, 1903.

¹⁰ Wegemann, C. H., The Powder River oil field, Wyo.: U. S. Geol. Survey Bull. 471, p. 61, 1912.

¹¹ Idem, p. 62.

¹² Wegemann, C. H., The Salt Creek oil field, Wyo.: U. S. Geol. Survey Bull. 670, p. 15, 1917.

¹³ Fisher, C. A., Southern extension of the Kootenai and Montana coal-bearing formations of northern Montana: Econ. Geology, vol. 3, pp. 77-99, 1908.

the true Dakota and the shale overlying the conglomerate may be the equivalent of the Fuson shale, of Lower Cretaceous age; he also suggests that the Dakota may be absent and that the shale and sandstone referred to may belong to the Benton.

Above the Morrison beds in the locality about 13 miles northwest of Hartville are from 250 to 300 feet of sandstones with several beds of shale and clay, which have been grouped together by Smith¹⁴ under the name Dakota sandstone. Smith says, however, regarding this method of grouping:

While it is possible and even probable that the lower part of this series of rocks corresponds to the Lakota (Lower Cretaceous) of the Black Hills, no formation corresponding definitely to the Fuson or Minnewaste was observed, so that the line of division between the Upper and Lower Cretaceous rocks (if the latter are represented) can not be drawn except arbitrarily. For this reason the rocks have been mapped without subdivision.

Many of the sandstones show distinct bedding, a few of them exhibit cross-bedding, and several present ripple-marked surfaces. The beds of clay or shale occurring with the sandstones are from 2 to 8 or 10 feet in thickness and of reddish, yellowish, or grayish color. In the Black Hills, on the opposite side of the Lance Creek field from the Hartville region, 150 to 350 feet of beds generally intervene between the Morrison beds and the Dakota sandstone. These beds seem to be the equivalent of the Lower Cretaceous rocks in other localities.

In the Newcastle quadrangle, for example, the Morrison is overlain by 150 to 200 feet of massive, cross-bedded, coarse gray to buff sandstone with local coal beds and conglomerate, known as the Lakota sandstone. This is overlain by 15 to 30 feet of gray to red shales with thin sandstones, known as the Fuson formation. Farther southeast, in the Edgemont quadrangle, the Lakota formation is from 200 to 350 feet thick, and between the Lakota and the Fuson formation is a limestone 25 feet in maximum thickness, which has been named in the Edgemont folio the Minnewaste limestone. This limestone is, however, not of widespread occurrence in the Black Hills. Its principal outcrops extend from the vicinity of Cascade Springs to Buffalo Gap, S. Dak., and it thins rapidly toward the south and west.

UPPER CRETACEOUS SERIES.

DAKOTA SANDSTONE.

The Dakota sandstone, as it has been definitely recognized in the Black Hills, ranges in thickness from 50 to 150 feet. In some places it is thin bedded in the upper part and massive in the lower part; in others it is entirely massive. It is ordinarily gray to buff and generally weathers brown.

¹⁴Smith, W. S. T., U. S. Geol. Survey Geol. Atlas, Hartville folio (No. 91), p. 3, 1903.

COLORADO GROUP.

The Colorado group in northeastern Wyoming includes the Niobrara formation, Carlile shale, Greenhorn limestone, and Graneros shale. The last three formations are equivalent to the Benton shale elsewhere. None of these formations are exposed at the surface in the Lance Creek field proper. They are well exposed in the Old Woman anticline, about 15 miles east of this field, and also in the Mule Creek oil field, about 30 miles northeast of the producing area in the Lance Creek field. The thickness and character of each of these formations are shown in the table on pages 95-96.

FORMATIONS EXPOSED IN THE LANCE CREEK FIELD.

The lowermost beds exposed in the Lance Creek field are those at the highest point on the anticline, in the western part of the field. They occur about 360 feet below the top of a sandstone which is probably the equivalent of the Shannon sandstone in the Powder River and Salt Creek fields. The formations that have been exposed by erosion in the Lance Creek field are described below.

CRETACEOUS SYSTEM.

PIERRE SHALE.

The Pierre shale occurs at the surface throughout the comparatively low area between the more or less continuous ridge formed by the Fox Hills sandstone on the north and the escarpment caused by the White River formation on the south. Being composed essentially of shale, it weathers down to a comparatively even surface. The bulk of the formation is composed of dark shale containing lenticular masses and more or less continuous beds of calcareous rock. The comparative hardness of the calcareous beds causes many of them to stand out above the general surface, and in places the succession of more or less independent jagged masses furnishes the only available key to the structure. These limy beds and lenticular masses, weathering, break up into a vast number of angular fragments and exhibit various kinds of fossil shells. Among the fossils collected from the upper portion of the Pierre shale during the process of the field work the following species were identified by T. W. Stanton:

- Actæon attenuatus* Meek and Hayden.
- Anchura* sp.
- Baculites ovatus* Say.
- Cucullæa shumardi* Meek and Hayden.
- Fish scale.
- Inoceramus barabini* Morton.
- Lingula nitida* Hall and Meek.
- Mactra gracilis* Meek and Hayden.
- Modiola meekii* (Evans and Shumard).

Mytilus? sp.

Ostrea sp.

Protocardia subquadrata (Evans and Shumard).

Scaphites nodosus Owen.

Syncyclonema rigida (Hall and Meek).

Yoldia evansi Meek and Hayden.

In many places where the shale is exposed a careful observer is able to detect thin layers of sandstone or thin seams of gypsum. One conspicuous layer of sandstone is exposed in the bottom of the gully between Rabbit Mountain and the main escarpment in the western part of sec. 4, T. 35 N., R. 64 W. A sandstone resembling it is well exposed at the north edge of the outlier of the White River formation near the north line of sec. 6 of the same township. Layers of sandstone show how the beds are inclined at numerous places in the east end of the field and furnish some clue as to structure in the western part, where most of the shale is concealed by the overlapping beds of the White River formation. In certain localities beds of the yellow clay known as bentonite occur in the shale and assist very materially in deciphering the structure. One of these beds forms the dip slope in the W. $\frac{1}{4}$ sec. 2, T. 35 N., R. 65 W., and appears to dip south at an angle of $3^{\circ} 6'$. A similar bed of bentonite, in all probability the same bed, is exposed on the north side of the anticlinal axis in the SE. $\frac{1}{4}$ sec. 26, T. 36 N., R. 65 W. There the bed of yellow clay dips north at an angle of 16° . The structure and also the total amount of the Pierre shale exposed in this field are indicated by thicker sands which occur in the upper portion of the Pierre and which are traceable for some distance on the surface.

The Shannon (?) sandstone crops out along the small gully immediately west of the No. 1 or discovery well, near the northwest corner of sec. 36, T. 36 N., R. 65 W. It rises gently toward the south, forming the dip slope, and arches over at the top of the anticline about 1,500 feet southwest of the discovery well. Scattered exposures of this sandstone were observed as far west as the center line of sec. 27. From dip determinations it is believed to lie about 1,300 feet below the base of the group of sandstones mapped as the Fox Hills sandstone. The gas well in the SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 34 is reported to have reached the first producing sand at a depth of 3,303 feet, whereas in the discovery well that sand was encountered at a depth of 3,663 feet. It is evident, therefore, that the beds which reach the surface at the gas well are about 360 feet below the top of the Shannon (?) sandstone, and accordingly about 1,660 feet of the Pierre shale is exposed in this field. Immediately overlying the Shannon (?) sandstone is a zone about 600 feet thick, including some soft sandy shale but composed mainly of dark shale with numerous fossiliferous calcareous concretions. Nearly all the beds from the top of this

zone up into the Fox Hills sandstone are exposed along the east bank of Lance Creek in the NE. $\frac{1}{4}$ sec. 28, T. 36 N., R. 65 W., as shown in the following section:

Section showing the uppermost part of the Pierre shale and the lowermost beds of the Fox Hills sandstone along the east bank of Lance Creek in the NE. $\frac{1}{4}$ sec. 28, T. 36 N., R. 65 W.

Fox Hills sandstone:	Ft.	in.
Sandstone, very light colored and very soft, not well exposed.....	25	
Sandstone, light yellow, soft and massive; contains a few concretions and rather uniformly distributed beds of hard reddish-brown sandstone from 6 to 18 inches thick.....	96	
Soft sandstone and sandy shale in thin beds; contains three thin beds of hard brown shelving sandstone showing numerous ripple marks.....	30	
Sandstone, light yellow, fine grained.....	1	
Sandstone and sandy shale in alternating layers of light yellow and dark color.....	3	6
Sandstone, massive, yellowish.....	3	
Sandstone, reddish brown, slabby; dip 24°.....		7
Sandstone, containing thin seams of sandy shale.....	4	
Sandstone, very massive, light yellow.....	7	
Sandstone, soft, containing thin beds of dark sandy shale and a few thin beds of hard sandstone, especially in the upper portion; strike east, dip 27° N.....	162	
Pierre shale:		
Shale, very dark, containing thin layers of reddish-brown sandstone; becomes much lighter colored near the top, as it merges into the Fox Hills formation; strike east, dip 27° N.....	72	
Sandstone; weathers to rounded surfaces; cut off abruptly by a shear zone.....	36	
Shale, dark; contains ten separate layers of reddish-brown concretions. <i>Baculites</i> fairly abundant. Strike east, dip at top 27 $\frac{1}{2}$ °.....	67	
Shale, dark, slightly sandy; contains very few concretions and is not very fossiliferous.....	120	
Interval, not well exposed but in all probability composed of very soft beds.....	100	
Belt composed essentially of soft sand but includes many thin seams of hard yellowish-brown sandstone.....	84	
Shale, very sandy.....	85	
Shale, grayish brown, sandy; weathers yellowish gray. Has many calcareous concretions which contain <i>Inoceramus barabini</i> Morton and <i>Anchura</i> sp. Dip 23° N. 40° W.....	34	

A 30-foot bed of soft light-gray sandstone included in the Lance Creek section is exposed in the NE. $\frac{1}{4}$ sec. 27, T. 36 N., R. 65 W. The bed was traced and mapped eastward to a point a few hundred feet east of the prominent butte composed of White River beds in sec. 25, T. 36 N., R. 65 W. Where the bed was last recognized it dips 20° N.

FOX HILLS SANDSTONE.

The great mass of Pierre shale is overlain with apparent conformity by many hundred feet of sandstones and sandy and carbonaceous shales, including some coal beds. A long period of time elapsed after the beginning of the influx of coarse sediments before there was a complete change from marine to brackish and fresh waters, and during that period the beds of the Fox Hills formation were laid down. After the formations were uplifted to their present position they were attacked by the agencies of erosion, but the overlying sandy beds, being harder and more resistant, were not removed as rapidly as the soft shales. As a result the area underlain by the Pierre shale is bordered on the north and west by a more or less continuous ridge underlain by the Fox Hills sandstone and the lowermost fresh and brackish water beds of the Lance formation. Most of the beds constituting the Fox Hills sandstone are exposed along the east bank of Lance Creek in the NE. $\frac{1}{4}$ sec. 28, T. 36 N., R. 65 W., and are shown in the stratigraphic section on page 102. There is a gradual transition from the Pierre shale to the Fox Hills sandstone, owing to the gradual influx of sandy material, but for the purpose of mapping the base of the Fox Hills was drawn at the base of the 162-foot zone as shown in the section, there being thus approximately 330 feet of the formation exposed at that locality. Throughout most of the Lance Creek field the formation is not well exposed, but farther north the Fox Hills and overlying "*Ceratops* beds" (Lance formation) and also some of the Pierre shale are much better exposed and are well described by Hatcher ¹⁵ as follows:

Along the southeastern border, especially between Lance and Buck creeks, are many fine exposures of the *Ceratops* beds and the underlying Fox Hills. Perhaps the best exposure is that made by a small tributary emptying into Buck Creek, about 4 miles east of Lance Creek and one-half mile northwest of the Buck Creek pens used by the cattlemen for round-up purposes. This watercourse has here cut its way in a southerly direction at right angles to the strike down through the lower half of the *Ceratops* beds, through the underlying Fox Hills sandstones, and into the Fort Pierre shales. At this place the bed of Buck Creek and the rounded hills of that region at the head of this stream, embraced between the border of the *Ceratops* beds and Fox Hills sandstones on the north and the bluffs of Miocene clays and conglomerates on the south, are composed of Fort Pierre shales. All the strata of this entire section dip to the northwest at an angle of 16 degrees. The exposure is a continuous one, and, commencing from below, the section is as follows:

At the base are the Fort Pierre shales, of unknown thickness, several hundred feet of which are exposed. They consist of argillaceous, finely laminated dark shales, quite soft and easily eroded. They contain many limestone concretions and numerous invertebrates. Among others are *Baculites ovatus*, *B. compressus*, *Scaphites nodosus*, *Platenticeras placenta*, *Nautilus dekayi*, etc.

Overlying the Fort Pierre deposits is an alternating series of sandstones and shales with an estimated thickness of 500 feet. In the lower portion of this series the shales

¹⁵ Hatcher, J. B., The *Ceratops* beds of Converse County, Wyo.: Am. Jour. Sci., 3d ser., vol. 45, p. 138, 1893.

predominate, but toward the middle the sandstones are in excess, and in the upper 50 feet they entirely replace the shales. The sandstones are of a yellowish-brown color, very fine grained, firm, and well stratified below, but softer and quite massive at the top, where they contain numerous large concretions and a rich marine invertebrate fauna. * * *

Next come the *Ceratops* beds, with an estimated thickness of 3,000 feet, resting directly upon the Fox Hills series. Immediately above the Fox Hills is a very thin but persistent layer of hard sandstone, well stratified, and easily cleavable along the lines of stratification. This stratum of sandstone is about 6 inches thick and is regarded as the dividing line between the marine and fresh-water beds.

In the geologic mapping the top of the Fox Hills sandstone is drawn at the 6-inch bed of sandstone, which Hatcher regards as the dividing line between marine and fresh-water beds. The sandstones which he mentions as containing numerous large concretions and a rich marine invertebrate fauna are exposed almost continuously along the west side of Buck Creek, and from the Buck Creek narrows as far east as the formation was mapped. They were also recognized in isolated exposures from the vicinity of Buck Creek as far west as Lance Creek. The appearance of these sandstones as they are exposed along the east side of Buck Creek valley is shown in Plate XII. The following fossils were collected from the Fox Hills beds at different localities in the Lance Creek field and identified by T. W. Stanton:

SE. $\frac{1}{4}$ sec. 33, T. 37 N., R. 63 W., from concretions in the sandstones near the top of the formation:

- Anchura* sp.
- Callista* sp.
- Crenella elegantula* Meek and Hayden.
- Cylichna scitula* Meek and Hayden.
- Dentalium gracile* Hall and Meek.
- Fish scale.
- Protocardia subquadrata* (Evans and Shumard).
- Scaphites conradi* (Morton)?
- Veniella humilis* Meek and Hayden.

NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 22, T. 36 N., R. 64 W., from concretions in the sandstones near the top of the formation:

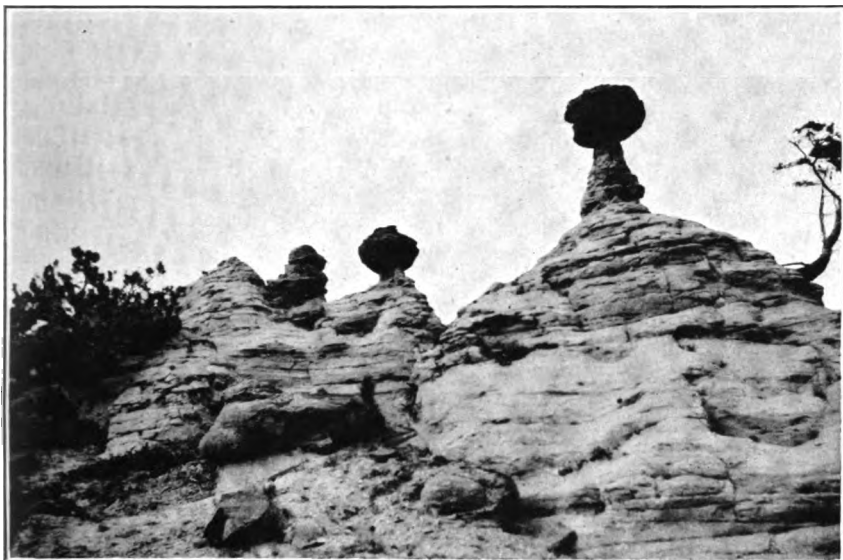
- Burrows of a boring mollusk.
- Veniella humilis* Meek and Hayden.

NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 20, T. 36 N., R. 64 W., from a sandstone about 100 feet above the base of the formation:

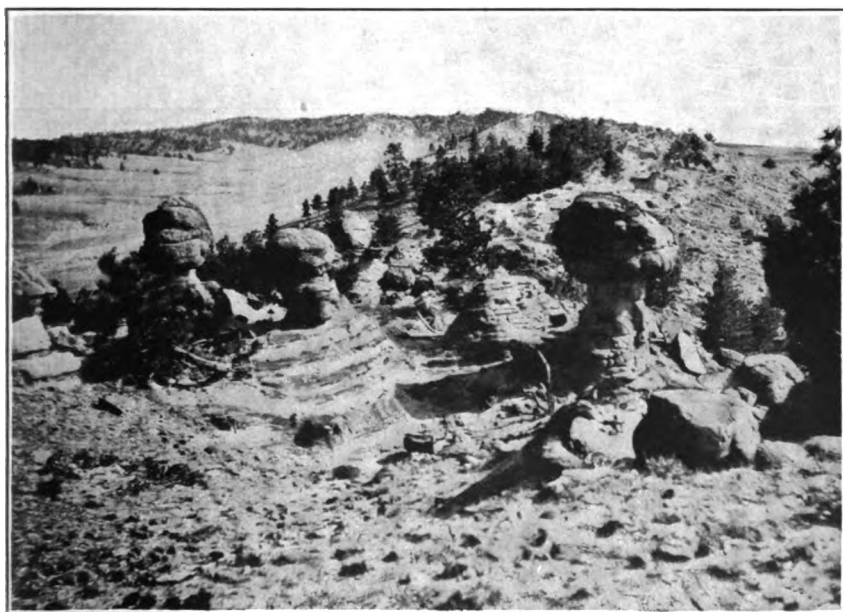
- Inoceramus* sp.
- Nucula* sp.
- Protocardia subquadrata* (Evans and Shumard).
- Scaphites conradi* var. *intermedius* Meek?
- Tellina scitula* Meek and Hayden.
- Veniella humilis* Meek and Hayden.

SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 12, T. 35 N., R. 66 W., from thin beds of sandstone exposed in the east bank of Little Lightning Creek:

- Avicula fibrosa* Meek and Hayden.
- Baculites ovatus* Say.



A.



B.

SANDSTONE INCLUDING LARGE REDDISH-BROWN CONCRETIONS NEAR THE TOP OF THE FOX HILLS SANDSTONE, EAST SIDE OF BUCK CREEK VALLEY, SEC. 33, T. 37 N., R. 63 W., WYO.

A, Showing results of weathering; **B**, View looking northwest. The tree-covered ridge at the top is developed, in part, on the same sandstone dipping westward on the opposite side of the valley.

Lucina subundata Hall and Meek.
Lunatia concinna (Hall and Meek)?
Nucula cancellata Meek and Hayden?
Scaphites conradi (Morton).
Veniella humilis Meek and Hayden?
Yoldia evansi Meek and Hayden.

TERTIARY (?) SYSTEM.

LANCE FORMATION.

The light-colored massive sandstones at the base of the Lance formation form Pine Ridge, in the SE. $\frac{1}{4}$ sec. 23, T. 36 N., R. 65 W. They crop out almost continuously as far east as sec. 12, T. 36 N., R. 64 W., but farther north and east they are not so conspicuous. West of Lance Creek these beds are well exhibited along the gulch extending southeastward through sec. 29, T. 36 N., R. 65 W., where the beds of the White River formation have been eroded and the uppermost Fox Hills and lowermost Lance beds appear, dipping 30° northwest. Toward the southwest they soon pass beneath the White River beds and are next seen in the SW. $\frac{1}{4}$ sec. 31 of the same township. Thence the beds can be traced continuously as far as the NE. $\frac{1}{4}$ sec. 12, T. 35 N., R. 66 W., but farther southwest they are entirely concealed. Where they were last recognized a brackish-water bed composed mainly of the shells and casts of *Ostrea subtrigonalis* dips 24° W. A similar brackish-water bed was seen near the east side of sec. 29, T. 36 N., R. 65 W., and shells of *Corbicula planumbona* Meek were collected near the control point at the top of the high ridge in the NW. $\frac{1}{4}$ sec. 22, T. 36 N., R. 64 W., from a layer of sandstone near the top of the conspicuous white sandstones that form Pine Ridge, about 4 miles farther west.

The writer was unable, for lack of time, to study the details of even the lower portion of the Lance formation in this field. He did, however, measure a section at Pine Ridge, in the SE. $\frac{1}{4}$ sec. 23, T. 36 N., R. 65 W., which shows fairly well the composition of the lower part of the formation. The base of the Lance formation is not well defined here, owing to the lack of good exposures, but the bottom of the following section is probably not far from that horizon.

Section of the lower beds of the Lance formation in the SE. $\frac{1}{4}$ sec. 23, T. 36 N., R. 65 W.

	Feet.
Soft sand and sandy shale containing thin beds of rusty-colored sandstone. The entire mass presents a pinkish color.....	9
Sandstone, light yellow, soft; weathers into cavern-like forms....	3
Shale, sandy; weathers pinkish.....	2
Sandstone, light colored.....	3
Sandstone, rusty colored; weathers into rounded forms.....	4
Sandstone, light brown, hard; forms conspicuous bed; weathers out into loglike forms.....	3

	Feet.
Shale and sand containing thin layers of sandstone; in weathering forms a pronounced pinkish to light-gray belt.....	35
Sandstone, lighter colored and softer than that below.....	18
Sandstone, yellowish brown, massive, very much in contrast with the white sandstone below; exhibits considerable cross-bedding.	60
Sandstone, very soft, containing a large amount of carbonaceous material.....	25
Sandstone, soft, thin bedded.....	6
Shale, dark gray; contains some carbonaceous material, very sandy at top.....	8
Shale, carbonaceous.....	2
Shale, dark gray.....	4
Sandstone, light yellow, soft and massive.....	6½
Coal (sandstones above and below show many fragments of fossil plants).....	5
Sandstone, soft; contains considerable carbonaceous shale.....	5
Sandstone, white, very massive; crops out at top of Pine Ridge..	15
Interval not well exposed but seems to consist mainly of sandy and carbonaceous shale, including thin beds of sandstone.....	25
Shale, black, carbonaceous; contains thin seams of coal and many thin streaks of sulphur.....	10
Sandstone, very white and massive; erodes into rounded surfaces.....	63
Sandstone, soft; contains several thin layers of hard reddish-brown sandstone which project above the surface.....	80
Shale, very sandy.....	40
Sandstone, rusty colored and hard.....	5

TERTIARY SYSTEM.

WHITE RIVER FORMATION.

After the Upper Cretaceous beds and those of the Lance formation, of doubtful Tertiary age, were uplifted to their present attitude they were deeply eroded, and finally, as a result of the oscillatory movements of the land, the waters again encroached upon the land area, and a considerable thickness of light-colored beds, now known as the White River formation, was laid down. That formation, in all probability, covered all of the Lance Creek field and lay as a horizontal sheet over the great arch of Cretaceous beds, but the agencies of erosion, such as wind, rain, and running water, have swept the beds from the crest of the arch and revealed that fold as a possible trap for the accumulation of oil and gas. If erosion had progressed still further the westward extension of the great anticline would be better known, for at present its west end is completely obscured by these horizontal beds. The northward limit of these beds is indicated by a rather well-defined escarpment and by outliers which form isolated buttes still farther north within the broad area occupied mainly by the Pierre shale. The formation is composed essentially of very soft, unconsolidated greenish-gray to white sand,

interbedded with reddish to greenish-gray shales. These beds are commonly overlain by greenish-gray, very coarse grained sandstone, in places coarsely conglomeratic. The reddish sandy shale near the base of the formation is sometimes mistaken for the "Red Beds" by those who are unfamiliar with the stratigraphy of the region.

QUATERNARY SYSTEM.

ALLUVIUM.

The only notable deposits of alluvium in this field are those which produce the rich, level land along Lance Creek. There the admixture of silts, sand, and gravel has been spread out from time to time as the stream has shifted its course.

STRUCTURE.

SALIENT FEATURES.

The Rocky Mountain front range and the Black Hills uplift are connected by what is commonly known as the Hartville uplift, an irregular arch whose axis is exhibited by exposures of granite, schist, and limestone near Hartville and Lusk, at Rawhide Butte, and at a number of other localities. The position of the axis is also indicated by the Old Woman anticline, which brings to the surface the uppermost beds of the Sundance formation. The Lance Creek field occupies a great arch or anticline of sedimentary beds west of the Old Woman anticline, from which it is separated by a shallow syncline. The crest of this arch can be traced with considerable accuracy for about 18 miles. It forms a reversed or sigmoid curve and extends from sec. 5, T. 35 N., R. 65 W., northeastward to the Ohio No. 1 or discovery well, near the northwest corner of sec. 36, T. 36 N., R. 65 W.; thence almost due east to a point one-eighth of a mile south of the center of sec. 25, T. 36 N., R. 64 W.; and thence a little east of north to the point where Buck Creek cuts across the Fox Hills escarpment, in sec. 29, T. 37 N., R. 63 W. The southwestward extension of the crest of the arch is obscured by the overlapping White River beds. The dip of the beds on the northwest flank of this great arch gradually steepens from 3° near its north end to 27° on Lance Creek, and from Lance Creek southwestward the dip is fairly uniform. The beds on the opposite flank of the arch dip southeastward for an indefinite distance at angles of $2\frac{1}{2}^{\circ}$ to 5° .

The Fox Hills sandstones, which at one time arched over the Lance Creek anticline, have been eroded away, leaving at the surface along the crown of the arch beds that lie several hundred feet below the top of the Pierre shale. The relatively low and even surface eroded on the shale is limited on the north by the conspicuous ridge formed by the Upper Cretaceous Fox Hills sandstone and on the

south by younger Tertiary beds, which conceal the older formations in that direction for many miles. The great arch of sedimentary beds is doubtless separated from the Hartville uplift by a broad syncline, but the western part of the syncline is obscured by the overlapping White River beds. The position of the east end of the synclinal axis can be recognized by opposite dips in sec. 36, T. 36 N., R. 64 W., and the SE. $\frac{1}{4}$ sec. 3, T. 36 N., R. 63 W.

METHOD OF REPRESENTING STRUCTURE.

Different methods have been used from time to time by the Geological Survey for the purpose of conveying to the reader an adequate notion regarding the structure, or what is frequently referred to by drillers and others as the "lay" of the beds. The structure is ordinarily shown by means of either structure sections or structure contours. The structure section is based mainly upon measurements of the degree of inclination of the beds at the surface and of stratigraphic thicknesses and upon data from deep borings. It shows how a portion of the earth's crust would appear if it were cut along a vertical plane and the portion on one side of the plane were removed. The section is an excellent aid in understanding the structure where the beds dip steeply, but where they are inclined only a few feet to the mile it is difficult to bring out certain structural features without exaggerating the vertical scale of the section, which is undesirable. In oil and gas investigations, where the interpretation and representation of structure are extremely important, the method of showing structure by contours has been adopted because of its practical value and also because it is easily understood. The following explanation is offered for the benefit of those who are unfamiliar with the definition, degree of accuracy, and practical application of structure contours.

Structure contours are lines drawn on a map to show the position of some particular stratum above or below a certain datum plane—for example, mean sea level. They are designed to show the shape and magnitude of the folds and in general the irregular warping of the beds. In the preparation of the accompanying map (Pl. X) it was decided to show throughout the field, as accurately as the data available would allow, the elevation of the top of the sand that yields most of the oil and gas. Any particular contour is the line of intersection between the top of the sand and a horizontal plane a certain distance (for example, 2,000 feet for the 2,000-foot contour) above sea level. Each structure contour represents a difference of 100 feet in position above or below the one adjacent, and hence it follows that where the contours are closely spaced the beds are steeply inclined, and where they are widely spaced the sand approaches much nearer to horizontality.

Structure contours furnish a convenient method for presenting a comprehensive idea regarding the structure of an entire field. Their practical value depends, of course, upon their accuracy, and the degree of accuracy depends upon the number of data available. In certain developed oil fields it is possible to obtain numerous well logs and to recognize in them, either directly or through the relation to other beds, the position of the particular bed which it is desired to contour. In such a field the depth at any point to the contoured bed can be ascertained very accurately by subtracting from the surface elevation the elevation of the bed as shown by the structure contour. In other fields, where little drilling has been done and especially where few of the records have been preserved, it is necessary to depend almost entirely upon surface data, such as dips, measured intervals between beds, and elevations on traceable beds. In such fields the structure contours are not likely to be drawn as accurately, but the demand for information is often so acute that it becomes necessary to sacrifice a certain degree of accuracy in order to insure more prompt publication. In the Lance Creek field the structure contours shown by broken lines are drawn on the basis of dips, measured intervals, and elevations on traceable beds. Those which are represented by unbroken lines are based entirely upon well records.

Throughout the field the contours near the base of the Fox Hills sandstone are reasonably accurate, because the Shannon (?) sandstone crops out near the discovery well, and, as explained on page 101, the dip determinations indicate a thickness of about 1,300 feet between that sandstone and the base of the Fox Hills formation. Southeast of the outcrop of the Fox Hills formation, in the eastern part of the field, the dips can be easily recognized, but there are very few beds in the Pierre shale that can be traced more than a few hundred feet. The writer obtained no well data from that portion of the field, and consequently the structure contours for it are less accurate. Practically all of the southwestern part of the field is overlain unconformably by the White River formation, of Oligocene age, and it seemed inadvisable to the writer to continue the structure contours any farther in that direction for fear of misleading those who studied the map without reading the text. The writer's views concerning the structure in the southwestern part of the field are stated briefly, however, under the heading "Suggestions for development" (p. 120).

OIL AND GAS.

GENERAL PRINCIPLES CONCERNING THE ORIGIN, MIGRATION, AND CONCENTRATION OF OIL AND GAS.

The primary source of petroleum is not definitely known, but most oil geologists believe that it is mainly of organic origin. It seems probable that most of the petroleum in the earth's crust has

originated from plants rather than animals, for two reasons—first, that the carbonaceous remains of plants are far more abundant than those of animals in the rocks; second, that the hydrocarbon-bearing parts of animals decompose more readily than the corresponding parts of plants. It has been estimated that more than 99 per cent of the carbonaceous material in the earth's crust is of plant origin. Aside from the water which they contain, plants consist mainly of elements that enter into the composition of petroleum and natural gas, namely, oxygen, hydrogen, and nitrogen. Although it is true that the soft parts of animals are composed mainly of the same elements, yet they decompose much more readily and therefore are more likely to be dissipated into the atmosphere or picked up by running water before being buried so deeply that oxidation and decomposition cease. In certain localities petroleum and natural gas have been found intimately associated with plant remains; in others these substances are more directly associated with the hard parts of animals, such as the shells of mollusks; but the great accumulations of petroleum and natural gas show conclusively that they migrate extensively. Hence it is generally very difficult to say whether these substances originated where they now occur, or whether they originated elsewhere and gradually migrated to their present situation as a result of the chemical and physical processes that are continuously at work within the earth's crust. The oil-bearing "sands" in the Lance Creek field are overlain and underlain by shales containing calcareous concretions, many of which are very fossiliferous. It seems possible that the oil now contained in the sands originated to some extent from the soft parts of the sea animals represented by the fossils, but probably it was derived mainly from carbonaceous material included in the dark shales themselves.

A careful examination of the structure of the rocks and its relation to concentration of oil and gas in many parts of the world has given rise to the structural or anticlinal theory. The conditions that control the accumulation of oil and gas, according to this theory, are briefly as follows:

1. A reservoir rock. This is commonly known as an oil sand, and as a rule it is porous, although it may be a very sandy shale, a fractured rock of any kind, a loose conglomerate sufficiently porous to allow the accumulation of oil or gas, or a limestone composed largely of interlocking crystals of calcite.
2. An impervious cap rock to seal over the reservoir rock and prevent the upward escape of the oil and gas.
3. Folds in the rock favoring the accumulation of oil and gas in certain places, these substances migrating from more extensive areas of adjoining beds that are less favorably situated for their retention.

4. Saturation of the rocks by ground water, on which the oil and gas will move on account of their lower specific gravity and be forced into the upper parts of the folds.

According to the anticlinal theory, if a porous rock containing gas, oil, and water is folded between other rocks that are nonporous these substances, under the influence of gravity, separate and arrange themselves according to density. The gas, being the lightest, rises to the crest of an anticline; the oil separates out below; and the water seeks the deepest portions of the beds. In accordance with the theory of organic origin it is believed that these substances were originally disseminated in the carbonaceous shales and limestones adjacent to the oil sands. Experience has shown, however, that the principal concentrations of oil and gas occur in the sands near the upper part of a fold. It is evident, therefore, that the fine particles of oil and gas have been forced out of the denser beds into the more porous sands and that this movement was followed by a slow migration up through the sands into the upper part of the fold.

Capillary attraction is in all probability an effective agent in the concentration of oil and gas. The size of the opening in rocks varies approximately with that of the constituent grains, being greatest in conglomerate and coarse sands and least in the clay shales. Inasmuch as water has about three times the surface tension of crude oil, capillary attraction must exert about three times as much force upon it. As the amount of the capillary pull varies inversely as the diameter of the pore, the tendency is for capillarity to draw water rather than oil into the smaller openings and to crowd the oil and gas into the more porous sands. It is believed that when, as a result of surface tension, the oil and gas have become segregated into bodies of considerable size, they arrange themselves under the influence of gravity and move upward through the pores of the sand under hydrostatic pressure. It has been shown by experiment that if a bubble of gas, in rising through water, comes into contact with a globule of oil the two unite and the oil forms a thin continuous film around the gas bubble. It seems probable, therefore, that the upward migration of oil is influenced considerably by the upward movement of bubbles of gas.

Detailed field observations have shown not only that many of the accumulations of oil and gas are intimately related to anticlines and domes, but also that gas, oil, and water are arranged in the manner indicated above. Although the recognition of these facts has caused most geologists to accept the anticlinal theory in its broader aspects, many of them are willing to accept it only in a modified sense, as recent study has shown that the accumulations of oil and gas occur not only in the crowns of arches but also in many places on the flanks where the dips are interrupted for some distance, the local flattening of the beds forming structural terraces.

Recent studies indicate also that the conditions of accumulation are entirely different in saturated and unsaturated rocks—that in thoroughly saturated rocks the oil and gas are borne upward on the sheet of underground water and are caught in the crowns of the arches, whereas in dry rocks the principal point of accumulation of oil is near the bottoms of synclines, or at any point where the forces obstructing the movement of the particles of oil are equal to or in excess of those which promote such movement. In saturated rocks the ideal structural form is a dome that includes a thick bed of porous sand effectively sealed above and dipping gently for a considerable distance, but such a form is not common in nature. In many domes the dips are interrupted by other structural features, and in consequence the collecting area is small. The oil sands may be lenticular, or, on the other hand, continuous sands may be offset along fault planes. If the fault remains partly open, fluids migrating through the porous sands rise to the surface and escape. It has been found that many oil seeps are accompanied by deposits of asphalt. If the fault is sealed by clay, asphalt, or some other impervious substance, the oil and gas may be concentrated in the sand near the fault plane and the result is practically the same as where the sand is lenticular. Thus an open fault fissure may prevent concentration at the top of an anticline or dome, and a fissure effectively sealed may produce local concentration at some point along the flank. The migration of oil, gas, and water through porous sands up along the flank of the most ideal structural feature may be retarded where the beds abruptly flatten or where the porosity of the sand decreases, and it may be entirely obstructed where a dike of igneous rock cuts across the sand.

From the facts above outlined it is not surprising that some accumulations of oil and gas occur in areas where from all surface indications the conditions are unfavorable, and that some areas which appear to have the most favorable structure are barren. These conditions are mentioned briefly, not with a view of questioning the value of the anticlinal theory as a working hypothesis, but merely to emphasize the necessity for making in every field a thorough study of all the conditions that may in any way retard the movement of fluids and the result in concentration.

RECENT DEVELOPMENT IN THE LANCE CREEK FIELD.

A few of the principal facts regarding early development in the Lance Creek field are given on pages 91-92, under the heading "History of development." Since the completion of the field work in June, 1919, several new wells have been completed, and before this report is available others will doubtless be drilled to the principal oil sand, so that, with respect to development, the facts shown on the accompanying geologic map (Pl. X) are incomplete. Wells at which,

according to recent reports in the oil journals, drilling has been discontinued are represented on the map as inadequately drilled. At certain wells the discontinuance was probably due to unfavorable results in neighboring wells; other wells may be only temporarily shut down. It will be some time before the limits of the pool are definitely determined, although the surface geology, together with the records of some of the wells that have already been drilled, strongly suggests the location of the most promising territory.

CHARACTER AND RELATION OF THE SANDS AS EXHIBITED IN WELL RECORDS.

Most of the wells that have been completed in the Lance Creek field range in depth between 3,300 and 4,000 feet, and the formation penetrated is almost entirely shale. There are, however, certain sands which were recognized in some of the wells and which doubtless could have been recognized in others if the drill cuttings had been more carefully preserved. The log of the discovery well is complete, and as it is probably typical of the field, it is given below.

Log of well No. 1,^a Ohio Oil Co., in the NW. $\frac{1}{4}$ sec. 36, T. 36 N., R. 65 W.

Driller's interpretation.	Thickness.	Depth.
	<i>Feet.</i>	<i>Feet.</i>
Muddy shale.....	6	6
Hard sandrock.....	19	25
Sandrock.....	55	80
Shale and soft sand.....	25	105
Hard rock.....	25	130
Hard shale and sandrock.....	15	145
Shale and mud.....	20	165
Muddy shale.....	20	185
Gummy shale.....	40	225
Gray shale.....	30	255
Shale.....	75	330
Tough gray shale.....	20	350
Shale; showing of gas at 2,070 feet.....	1,720	2,070
Gray shale with shells.....	35	2,105
Hard shell.....	10	2,115
Shale.....	175	2,290
Gray shale.....	40	2,330
Whiteslate.....	20	2,350
Shale.....	75	2,425
Shale with shells; gas at 2,425 feet.....	15	2,440
Sandy shale.....	65	2,505
Hard shell.....	2	2,507
Sandy shale.....	58	2,565
Gray sandy shale.....	15	2,580
Broken sand; trace of oil at 2,615 feet.....	50	2,630
Sandy shale.....	30	2,660
Shale.....	29	2,689
Oil sand [Wall Creek sandstone].....	12	2,701
Shale.....	19	2,720
Sandy shale.....	10	2,730
Shale.....	78	2,808
Soft shale.....	178	2,986
Shale, color changeable.....	90	3,076
Soft black shale.....	130	3,206
Shale.....	27	3,233
Hard shell.....	17	3,250
Shale.....	83	3,333
Dark lime.....	127	3,460
Shale.....	197	3,657
Hard shell.....	6	3,663
Sand (oil sand).....	24+	3,687+

^a The Ohio Oil Co. has several wells designated No. 1, and to identify the well the number should be read in connection with the location.

It is possible to recognize in the above and other logs the several sands in the Lance Creek field, and for convenience they are discussed below in the same order as they are encountered in drilling.

SHANNON (?) SANDSTONE.

The sandstone that is regarded as probably the same as the Shannon sandstone of the Salt Creek field crops out along the gully immediately west of the discovery well, near the northwest corner of sec. 36, T. 36 N., R. 65 W. It rises gently toward the south, forming a dip slope, and arches over the top of the anticline about 1,500 feet southwest of the discovery well. Exposures of this sandstone were observed here and there as far west as the center line of sec. 27. In some places along the outcrop the sandstone is only about 16 feet thick, but in others it is much thicker. It is coarse grained, has a greenish-gray color, and contains many yellowish-brown iron-stained concretions. At the top there are many small dark-colored concretions which, upon weathering, become light gray. The log of the discovery well as given above shows sandy beds extending from 6 to 145 feet beneath the surface, but the exposures along the outcrop did not indicate so great a thickness.

In the Ohio Oil Co.'s well No. 1 near the northwest corner of sec. 31, T. 36' N., R. 64 W., the Shannon (?) sandstone is probably represented by a 38-foot sand whose top lies at a depth of 195 feet, and in the Midwest Refining Co.'s well No. 3, in the SW. $\frac{1}{4}$ sec. 25, T. 36 N., R. 65 W., it is represented by 40 feet of gray sandrock beginning at a depth of 40 feet. It is also exhibited in the log of the Ohio Oil Co.'s well No. 1 in the SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 32, T. 36 N., R. 64 W., as a hard sand containing a little water and extending from 300 to 330 feet beneath the surface. The sandstone lies near the surface at the Ohio No. 1 and Buck Creek No. 7 wells, near the center of sec. 35, T. 36 N., R. 65 W., and is eroded from the higher portion of the anticline farther west, where the gas wells are situated. If, as explained on page 101, the two bentonite beds on opposite sides of the anticline are the same, the Shannon (?) sandstone should dip beneath the surface on the southeast side of the anticline, near the Midwest well No. 1, in the NE. $\frac{1}{4}$ sec. 3, T. 35 N., R. 65 W., but it was not recognized there.

WALL CREEK SANDSTONE.

It is possible to recognize in many of the well logs in this field a sandy zone approximately 1,050 feet above the principal oil sand. In the discovery well this zone extends from 2,580 to 2,701 feet beneath the surface, and its top is 1,083 feet above the top of the principal oil sand. In some of the well logs this material is recorded as sand, in others as sandy shale, and in a few as alternating beds of

shale and sand containing some oil and gas. The stratigraphic position of these sandy beds is similar to that of the Wall Creek sandstone in the Powder River and Salt Creek fields, the sandstone at the top of the eastern anticline in the Mule Creek field, and the sands that yield oil in the Upton-Thornton field. Although none of the wells in the Lance Creek field are producing oil from this sandstone, it has given promise of yielding a fair output in some of the wells and should be watched carefully and recorded in the logs as accurately as possible.

PRINCIPAL OIL AND GAS SANDS.

The formations included between the base of the Sundance and the top of the Dakota are discussed in considerable detail on pages 96-99, and the subdivisions of the Colorado group are mentioned on page 100, but inasmuch as the sands near the base of the Colorado do not crop out in the Lance Creek field but are exposed not far distant, it seems appropriate to study some of the lower beds first as they are exposed elsewhere and later as they are exhibited in some of the well logs of this field. Northeast of this field, in the vicinity of Newcastle, the Dakota sandstone is immediately overlain by about 225 feet of dark shale that erodes very readily, producing a relatively low area between the long dip slope formed by the Dakota sandstone and the more or less jagged ridge formed by a sandstone that overlies this shale. The extent of this sandstone along the flanks of the Black Hills uplift and outward from that uplift is a matter of vital interest to oil and gas operators, not only because oil issues from it in considerable quantities at Newcastle but also because it is one of the main oil-producing sands at other localities in Wyoming. In the Upton-Thornton field it occurs as a reddish-brown, moderately soft sandstone encircling the central portion of the Thornton dome and occurring as isolated patches near the top of the dome. It is apparently only 2 or 3 feet thick at the northwest end of the dome, but at the south end it includes about 15 feet of reddish to light-yellow sandstone associated with some carbonaceous shale. In the vicinity of Newcastle, where considerable oil seeps from the sand, it is about 35 feet thick and forms a ridge about 500 feet above the railroad.

It continues as a very conspicuous ridge as far southeast as the L. A. K. ranch, on Stockade Beaver Creek, but from that locality southward it becomes thinner, appearing only at intervals as lenses in the shale. It seems to be rather well developed, however, near the north end of the Old Woman anticline, a few miles east of the Lance Creek field. The conditions there are set forth below.

About three-fourths of a mile northwest of Wright's camp the Dakota sandstone forms a long dip slope. The sandstone is overlain

by about 200 feet of dark shale, and the shale is in turn overlain by a succession of sandstone and carbonaceous shale beds almost 38 feet thick, which give rise to a very conspicuous ridge. This group of beds, the details of which are shown in the following section, is in all probability equivalent to the oil-bearing sand at Newcastle.

Section near north end of Old Woman anticline.

	Ft.	in.
Sandstone, very hard, forming east dip slope.....	2	6
Interval, mainly black carbonaceous shale.....	9	
Sandstone, yellowish brown, massive.....	6	6
Shale, sandy, carbonaceous.....		9
Sandstone, rather thinly bedded.....	7	
Shale, black, carbonaceous.....	5	6
Sandstone, yellowish brown, hard and massive.....	4	6
Shale, sandy.....	1+	
	36	9+

The group of sandy beds described above is doubtless widely distributed throughout Wyoming. The beds were recognized by the writer on the south slope of Como Ridge, about 6 miles east of Medicine Bow, and are in all probability equivalent to the sand that occurs near the middle of the Thermopolis shale at different localities in Big Horn Basin, commonly known by drillers as the Muddy sand. In the writer's recent report on the Mule Creek oil field¹⁸ this sand was named the Newcastle sandstone member of the Graneros shale, because at Newcastle it is of unusual thickness and contains oil. It is the writer's opinion that the principal oil and gas sands in the Lance Creek field are the stratigraphic equivalent of the Newcastle sandstone and should be called by that name.

In the Lance Creek field the Newcastle sandstone is usually composed of two distinct beds of sand separated by a layer of hard sandy shale, and in that respect it resembles a portion of the section near Wright's camp, at the north end of the Old Woman anticline. (See above.) The upper sand varies considerably in thickness and averages about 20 feet. The shale interval between the upper and lower sands also varies considerably, but the average thickness is about 15 feet. Evidence concerning the thickness of the lower sand is lacking, for in most borings the drill has penetrated only a portion of the sand, but the total thickness of the two sands and the intervening shale is probably not greater than 50 feet. As a result of lenticularity, variable porosity, or some other property of these sands, the results of drilling have in certain places been somewhat disappointing. The behavior of gas, oil, and water in the wells is a subject that requires special study, and after more data are available such a study should be made for the purpose of determining how the physical and chem-

¹⁸ Hancock, E. T., The Mule Creek oil field, Wyo.: U. S. Geol. Survey Bull. 716, p. 42, 1920 (Bull. 716-C).

ical properties of the sands influence the migration and accumulation of these substances.

RESULTS OF DRILLING.

At present it is impossible, with the meager data at hand, to tabulate more than a few of the results of the drill. The facts set forth in the following table have been obtained from various sources, mainly since the field work was completed, and although some of the depths shown may be slightly in error they are believed to be essentially correct. The information relating to well logs obtained by the writer in the course of the field work was supplemented by additional data obtained through F. B. Tough and B. H. Scott, of the United States Bureau of Mines, relating to the composition of the principal oil sand in some of the wells recently completed.

Results of drilling in most of the wells completed in the Lance Creek field.

Company.	No. of well.	Location.				Depth to top of upper sand (feet).	Elevation of top of upper sand about sea level (feet).	Contents of sand.	Reported production, with authority.
		Quarter.	Section.	Township N.	Range W.				
Midwest Refining Co.	1	NE....	28	36	64	3,965	500	Oil in upper sand.....	1,200 barrels a day, initial production: Wyoming Oil News, Sept. 6, 1919.
Ohio Oil Co.	1	NE....	33	36	64	4,138	362	Water in upper sand.....	
Do.	1	NW....	31	36	64	3,850	572	Water in upper and lower sands.	
Do.	2	NW....	36	36	65	3,702	700	Oil in lower sand.....	250 barrels a day: Wyoming Oil News, Sept. 6, 1919.
Do.	1	NW....	36	36	65	3,663	748	Oil in upper sand.....	1,200 barrels a day initial production: Oil and Gas Jour., Oct. 18, 1918. Settled production 400 barrels: Wyoming Oil News, Sept. 6, 1919. Flush production, 2,000 barrels Wyoming Oil News, Oct. 18, 1919. Later production 1,100 barrels: Wyoming Oil News, Sept. 6, 1919.
Do.	5	NW....	36	36	65	3,744	725	* Oil in lower sand.....	800 barrels a day: Wyoming Oil News, Sept. 6, 1919.
Midwest Oil Co.	33	NE....	3	35	65	3,665	743	Water in upper sand.....	1,300 to 1,500 barrels: Oil Trade Jour., December, 1919.
Buck Creek Oil Co.	28	NE....	35	36	65	3,668	779	Oil in upper and lower sands.	
Do.	14	NE....	35	36	65	3,632	789	do	
Do.	4	SE....	26	36	65	3,950	740	Oil in upper sand.....	
Do.	7	NW....	35	36	65	3,668	816	Oil in third sand.....	Estimated initial production, 50,000,000 cubic feet: Oil and Gas Jour., Oct. 25, 1918.
Do.	1	SW....	34	36	65	3,400	985	Gas in upper sand.....	30,000,000 cubic feet: Oil and Gas Jour., Oct. 2, 1919.
Do.	27	NW....	34	36	65	3,303	1,052	do	Estimated initial production, 8,000,000 cubic feet.
Midwest Refining Co.	1	SW....	27	36	65			Water in upper sand.....	600 barrels a day: Wyoming Oil News, Sept. 6, 1919.
Buck Creek Oil Co.	30	SE....	34	36	65	3,585	880	Gas in upper sand.....	Flush production, 2,500 barrels: Wyoming Oil News, Dec. 27, 1919. Production Jan. 10, 1920, 1,800 barrels a day: Ohio Oil Co.
Ohio Oil Co.	1	NE....	4	35	65	3,405	1,006	Water in upper and lower sands.	
Western States Oil Co.	1	SE....	3	35	65	3,940	855	Oil in lower sand.....	
Ohio Oil Co.	1	NW....	3	35	65	3,527	955	do	
Do.	3	NW....	36	36	65				
Do.	1	SW....	4	35	65	3,556	921		
Do.	2	NE....	4	35	65	3,479	960	Water in upper sand (?)	

Most of the figures of production in the above table indicate the supposed production September 6, 1919. Some of the estimates of flush production, as given in the oil journals, are probably too high. The Wyoming Oil News summarizes the situation in the Lance Creek field by saying: "The present production of oil is around 4,650 barrels per day, with some of the wells pinched down. The capacity of the gas wells is around 150,000,000 cubic feet per day."

Most of the oil from the Lance Creek field is conducted through a pipe line to the Chicago & Northwestern Railway at Lusk, Wyo., and there emptied into tank cars ready for shipment to the refineries. According to the Oil Trade Journal of November, 1919, the Ohio Oil Co. then expected to have in operation in about three months the first unit of what will eventually become a large absorption plant for the manufacture of casing-head naphtha. The original plan was to install a high-pressure plant that would treat 10,000,000 cubic feet of gas a day, but later it was decided to install a low-pressure plant that will handle the gas at a pressure of 30 pounds instead of 80 to 100 pounds.

On the higher portion of the anticline the upper sand generally shows high gas pressure. In wells Nos. 1 and 27 of the Buck Creek Oil Co., in sec. 34, T. 36 N., R. 65 W., and in well No. 1 of the Ohio Oil Co., in sec. 4, T. 35 N., R. 65 W., the gas seems to occur in large volumes and the rock pressure is reported to be nearly 1,000 pounds to the square inch. This is probably also true of the two gas wells of the Midwest Refining Co., one near the south quarter corner of sec. 27 and the other in the NE. $\frac{1}{4}$ sec. 33, T. 36 N., R. 65 W., but the writer is unable to verify this statement. It is probable that the lower limit of gas in the upper sand on the axis of the anticline is not far west of the group of wells in the NE. $\frac{1}{4}$ sec. 35, T. 36 N., R. 65 W., as well No. 28 of the Buck Creek Oil Co. is reported to have given a strong showing of gas when the drill entered the first sand, but as the well was drilled deeper the proportion of oil greatly increased. Farther west the body of gas lies structurally as low or even lower along the northwest flank of the anticline but apparently not as low along the southeast flank.

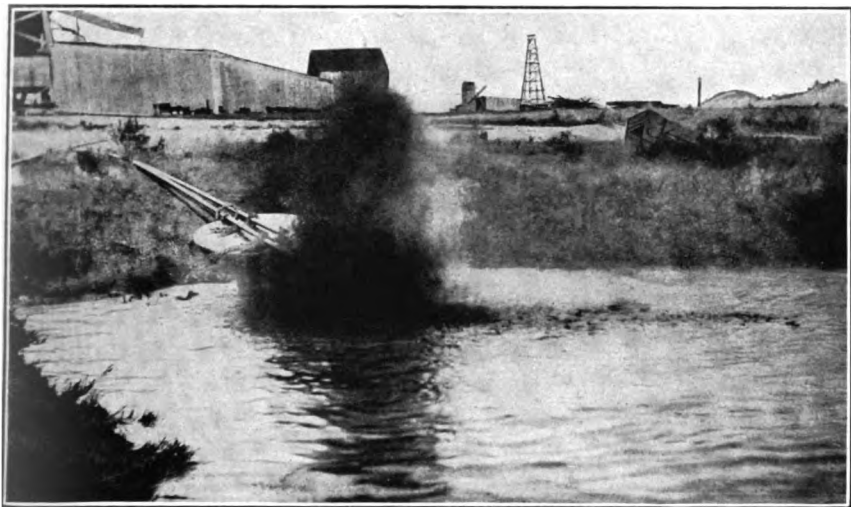
After the discovery well was drilled in, the oil rose to the surface and discharged into the earthen storage reservoir with great force, as shown in Plate XIII. This flow took place at intervals of approximately one hour and lasted for about 30 minutes each time. Tanks to hold the oil were constructed as rapidly as possible, and finally the oil was turned into the pipe line. There is in all probability a body of oil below the gas which is trapped in the upper part of the fold, but neither the upper nor the lower limit of the oil can be determined until further drilling is done. The few wells that have been drilled

indicate that the main body of oil occurs at a lower level along the northwest flank of the anticline than it does along the southeast flank.

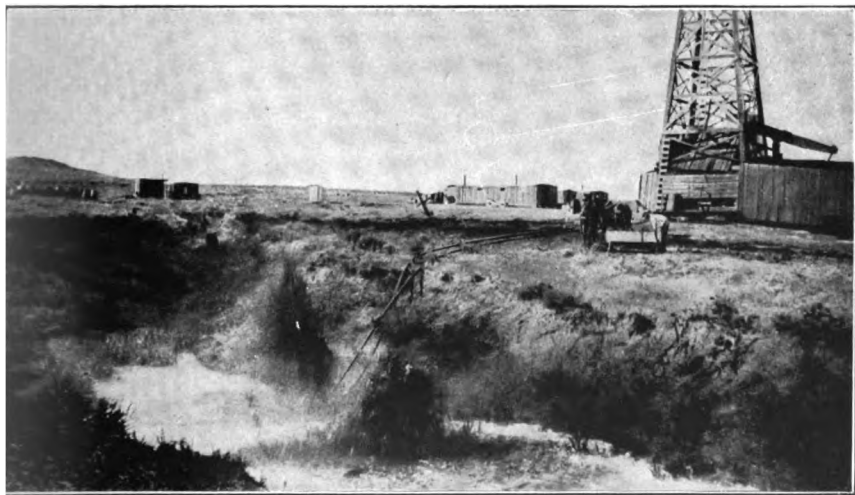
The two wells (Nos. 30 and 33) near the southeast corner of sec. 34, T. 36 N., R. 65 W., are shown as water wells, as it is reported that water was encountered in each well in the upper sand. Deeper drilling may prove that the lower sand contains oil, and if through skillful manipulation the upper sand is properly cased off, these wells may still become producers. It was reported that early in January the Ohio Oil Co. was at work cementing off the water in the upper sand in its No. 2 well in the NE. $\frac{1}{4}$ sec. 4, T. 35 N., R. 65 W. The peculiar occurrence of oil and water in the upper and lower sands, as shown in the above table, indicates that the upper sand should invariably be carefully tested. If the supply of oil is not satisfactory this sand should be mudded and a string of pipe put through it and cemented before drilling into the lower sand. If the upper sand is nonproductive and yet does not contain water, this practice will prevent the oil and gas under high pressure from the lower sand from escaping into the upper sand. If the upper sand is water bearing and the lower sand is productive it will prevent the productive sand from being flooded as soon as the rock pressure in this sand becomes lower than the water pressure exerted from the upper sand.

SUGGESTIONS FOR DEVELOPMENT.

According to the writer's interpretation of the structure there is little probability of finding in the area east of T. 36 N., R. 65 W. pools of oil comparable to that which lies in that township and the one immediately south, and yet it seems reasonable to expect that some oil may have accumulated near the axis of the anticline, at least as far east as the east line of sec. 26, T. 36 N., R. 64 W. North-east of that line the anticlinal axis is more steeply inclined and the conditions are not quite as favorable. The two water wells in sec. 31, T. 36 N., R. 64 W., one near the northwest corner and the other near the north quarter corner, suggest a slight lowering of the anticlinal axis at that locality. If such is the case there is probably a corresponding rise in the axis immediately east of that place and a slight closure a short distance west of well No. 1 of the Midwest Refining Co. in sec. 28. The field evidence seems to indicate that the anticlinal axis pitches eastward rather rapidly from that point. If the structure is as shown, the gas, oil, and water would naturally migrate up the steeply dipping sands, mainly from the northwest, and finally tend to accumulate where the axis becomes more nearly horizontal or where it is gently arched. If the Newcastle sand is reasonably thick and porous and continues northwestward from the anticlinal axis for a considerable distance, it is reasonable to expect a certain amount of



A.



B.

DISCHARGE OF OIL INTO A DAMMED-UP GULCH AT THE OHIO OIL CO.'S
DISCOVERY WELL IN THE NW. $\frac{1}{4}$ SEC. 36, T. 36 N., R. 65 W., LANCE CREEK
FIELD, WYO.

concentration in the sand near the anticlinal axis and for some distance down the dip, especially north of the axis. The most promising territory lies west of the east line of sec. 26, T. 36 N., R. 64 W., because there the anticlinal axis is more nearly horizontal and also because farther east the depth of the sand increases very rapidly. The best part of this promising territory appears to lie southwest of the developed portion of the field, more or less in line with the hypothetical anticlinal axis, as indicated on Plate X by the broken line extending across secs. 5 and 8. The abrupt rise in the anticlinal axis from the vicinity of the discovery well westward is the natural result of the abrupt change in the strike of the beds. If the strike continues in a southwesterly direction for a considerable distance beyond this abrupt change, then the anticlinal axis in all probability also pitches toward the southwest. The trend of the structure contours southeast of the anticlinal axis seems to indicate that the higher contours close around the fold rather quickly and that the axis pitches in a southwesterly direction, very much as it does from the highest portion of the anticline eastward toward the discovery well.

Other sands lower than those which have been tested in the Lance Creek field should ultimately be tested near the highest portion of the Lance Creek anticline. It is the writer's belief that in the Mule Creek field the oil comes from a portion of the Lakota sandstone. In the Greybull field the Greybull sandstone member of the Cloverly formation produces most of the oil and gas. In the Powder River field the approximate stratigraphic equivalent of the Cloverly, which was designated the Dakota (?) sandstone, is the principal oil-bearing formation, but a small quantity of oil occurs in at least two sands in the Morrison and also in the Sundance formation. In the Lander field the Carboniferous portion of the Embar group bears some oil, and a 1,730-foot boring on the Old Woman anticline, a short distance east of the Lance Creek field, is reported to have found considerable oil, doubtless in the Minnelusa sandstone, also of Carboniferous age.

In an area structurally so promising as the producing portion of the Lance Creek field, it seems advisable for the different operating companies to combine, if possible, and drill at least one well near the top of the fold in order to test all the sands, or at least all including those in the Sundance formation. According to the table of formations on pages 95-96 all these sands could be tested by drilling to a depth of approximately 4,200 feet.

QUALITY OF THE OIL AND GAS.

The following analysis of a sample of oil from the Ohio Oil Co.'s discovery well is fairly typical of most of the oil in the Lance Creek field. A much heavier black oil is reported, however, from the Buck Creek Oil Co.'s No. 7 well in the NW. $\frac{1}{4}$ sec. 35, T. 36 N., R. 65 W.

Analysis of oil from discovery well of Ohio Oil Co. in the NW. $\frac{1}{4}$ sec. 36, T. 36 N., R. 65 W.

[Made in the laboratory of the Bureau of Mines. Distillation in Bureau of Mines Hempel flask. Amount distilled, 200 cubic centimeters. Depth of well, 3,666 $\frac{1}{2}$ feet; depth to principal oil sand, 3,663 feet.]

Gravity at 15° C.:

Specific.....	0. 807
Baumé.....degrees..	43. 5

Air distillation, with fractionating column:

Barometer reading.....	millimeters..	740
Distillation begins.....	degrees C..	25
To 150° C.:		

Total distilled by volume.....	per cent..	29. 8
Specific gravity (125°-150°).....		0. 760

150° to 300° C.:

Total distilled by volume.....	per cent..	32. 9
Specific gravity (275°-300°).....		0. 825

Vacuum distillation, without fractionating column (175°-300°):

Pressure.....	millimeters..	39
Total distilled by volume.....	per cent..	21
Residuum.....	do....	16. 3
Sulphur.....	do....	0. 043

The gasoline content of the gas from three of the wells of the Ohio Oil Co. in the Lance Creek field, as shown by an absorption test made by J. K. Gibson, of the Hope Natural Gas Co., is shown by the following data, which were furnished by the Ohio Oil Co.:

Data on gas wells of Ohio Oil Co.

Well No.	Location.				Volume of gas (cubic feet per day).	Pressure at which test was made (pounds to the square inch).	Specific gravity of gasoline recovered.	Gasoline content (gallons per 1,000 cubic feet of gas).
	Quarter.	Section.	Township N.	Range W.				
1.....	NW.....	36	36	65	800,000	42	0. 712	1. 184
1.....	NW.....	3	35	65	4,500,000	75	. 778	1. 27
1.....	NE.....	4	35	65	8,000,000	100	. 760	1. 153



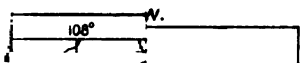
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BULLETIN 716 PLATE X



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DEPARTMENT OF THE INTERIOR

JOHN BARTON PAYNE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 716—F

COAL IN EASTERN IDAHO

BY

GEORGE R. MANSFIELD

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COAL IN EASTERN IDAHO.

By GEORGE R. MANSFIELD.

INTRODUCTION.

The general coal shortage in the winter of 1916-17 was particularly acute in eastern Idaho, notwithstanding the relative proximity of this area to the coal fields of western Wyoming. The mines of the Horseshoe district, on the west side of the Teton Basin, afforded some relief but were unable to supply the demands of the region.

In the summer of 1917, in response to urgent requests by residents of eastern Idaho, the United States Geological Survey undertook the investigation of certain reported coal fields in that part of the State to determine if there were any lands that could be classified and appraised as coal land and thus made available for local mining, so that the threatened shortage for the ensuing winter might be averted.

The writer, who was detailed to make the examination, spent about two months in the summer of 1917 with camp outfit and two helpers visiting the reported localities and mapping the geology of portions of the country.

SCOPE OF INVESTIGATION.

The territory examined falls in general within four districts—(1) the Willow Creek-Caribou district, southwest of Snake River, including prospects on Willow Creek, on Grays Lake Outlet, and in the Fall Creek basin; (2) the Pine Creek district, northeast of Snake River, including the land between the head of Pine Creek on the northwest and Palisade Creek on the southeast and also Burns Canyon; (3) Teton Basin, Teton County, including the valleys of Horseshoe, Mahogany, Patterson, and Trail creeks; (4) the Continental Divide district, Fremont County, in T. 14 N., Rs. 38 and 40 E.

In addition to these districts, two prospects were reported to the writer while he was in the field—one at Heise, in the SE. $\frac{1}{4}$ sec. 25, T. 4 N., R. 40 E., and the other at Barney's ranch, 4 miles up Canyon Creek from the former Canyon Creek post office. At Heise conditions proved to be similar to those seen at the Willow Creek locali-

ties, but the prospect at Barney's ranch, which was stated by the writer's informant to be probably on an occurrence of obsidian, was not visited.

In this report only such geologic data are presented as have a direct bearing on the occurrence and usability of the coal.

MAPS.

The general map (Pl. XIV) shows the location of the region examined and the distribution of the general geologic and other features. This map also shows the location of the principal prospects and exposures examined where detailed work was not done. Plate XV and figure 13 show, respectively, on a larger scale the Pine Creek and Teton Basin region and the area in T. 14 N., Rs. 38 and 39 E., near the Continental Divide.

SUMMARY OF RESULTS.

The results of the examination are disappointing. In the Willow Creek-Caribou and Pine Creek districts coaly shale, with some impure coal, is present in beds ranging in thickness from a few inches to 7 feet or more. As a rule the coaly portions of these beds are not persistent but wedge in and out. Lumps of usable coal may be obtained here and there, but commercial development seems to be impracticable. The rock formation in which these coal beds occur is not the one in which the active mines of western Wyoming are located.

The only part of the Teton Basin that is producing coal at the present time is the Horseshoe district. Though conditions in this district are such that large-scale development is probably impracticable, work now in progress will doubtless make possible a somewhat greater yield than that of previous seasons. There is little chance that workable coal beds will be discovered elsewhere in the basin.

On the Continental Divide in T. 14 N., R. 38 E., a 32-inch bed of good coal was found, but the area in which it crops out is not large and its remoteness from lines of transportation and a suitable market make its early exploitation doubtful.

In the districts examined two substances occur that are commonly mistaken for coal, namely, phosphate rock and obsidian, a black volcanic glass. The phosphate rock in these districts when distilled yields a small quantity of petroleum, is unusually black, and has a gloss that makes its appearance very deceptive, as in the Patterson Creek, Burns Canyon, and Palisade Creek localities, where this rock has hitherto been regarded as coal.

During the examination of the Teton Basin several reported occurrences of oil were investigated, but these do not indicate the presence of oil in paying quantities.

ACKNOWLEDGMENTS.

The writer is indebted to the United States Forest Service and particularly to officers of the Caribou, Palisade, and Targhee national forests for maps and the free use of their field facilities. A. R. Schultz,¹ D. D. Condit, and E. H. Finch, of the Geological Survey, have kindly permitted the use of manuscript maps and reports relating to portions of the region visited. The published work of earlier geological surveys has been drawn upon in the preparation of both the general map and the text and will be specifically acknowledged on later pages. Mr. J. A. Cloward, whose ranch is on Willow Creek, in sec. 6, T. 1 N., R. 40 E., furnished valuable information. Mr. L. Hillman, of Driggs, Idaho, manager of the Teton Valley Coal Co., was kind enough to show personally the workings of the Brown Bear and Boise mines. Mr. L. Perry, of Bates, Idaho, took the writer to see several prospects on Mahogany Creek and in the vicinity of Teton. Information from other sources will, so far as practicable, be acknowledged below.

SURFACE FEATURES OF THE COUNTRY.

The region here described lies in the southeastern part of Idaho, in Fremont, Jefferson, Madison, Teton, Bonneville, and Bingham counties, and includes the east end of the Snake River plains, with their mountainous borders, which have been so vividly and admirably described by Russell.²

The Blackfoot, Caribou, Snake River, and Big Hole ranges, which form the rugged mountain border in the southeastern part of the district, are composed of folded and broken sedimentary rocks that represent many geologic periods and vary considerably in resistance to weathering and erosion. These rocks have been subjected to more than one cycle of uplift and erosion, so that broad valleys or basins have been excavated along the strike of the relatively weaker rocks, such as certain sandstones, shales, and clays, while harder rocks, such as massive limestones, sandstones, or quartzites, have formed prominent peaks and ridges 7,000 to 9,000 feet or more in general elevation and cut by narrower transverse canyons or gulches. The broader valleys, 1,000 to 3,000 feet lower and occupied in part by lava, together with the adjacent transverse valleys and gulches,

¹ Mr. Schultz's report has since been published as U. S. Geol. Survey Bull. 680, 1918.

² Russell, I. C., *Geology and water resources of the Snake River plains of Idaho*: U. S. Geol. Survey Bull. 199, 1902.

have been deepened and sharpened by the erosion of later epochs to dimensions varying with the locality and the character of the rock. The most impressive of these renewed canyons is that of Snake River.

The east side of Teton Basin is formed by the lava-covered western foot slopes of the Teton Range, which a few miles to the east of this district culminates in beautiful alpine peaks that serve as landmarks for a wide region and are known as the Tetons. The Grand Teton, 13,747 feet above sea level, is the highest. The lavas of Teton Basin are continuous northward with those that lap around the north end of the Teton Range and merge with the volcanic plateau of the Yellowstone, which forms the northeastern border of the district.

On the north in the region described in this report the Snake River plains are bordered by lavas that rise gently to the Continental Divide. The lavas in all probability once completely covered this portion of the region, but they have been considerably dissected, so that here and there relatively recent conglomerates and older sedimentary rocks are exposed. Lava cliffs and hard sedimentary rocks now form the high and rugged mountains along the divide as viewed from the south. Where weaker sedimentary rocks have been exposed by erosion the divide is lower. According to Forest Service maps some of the higher peaks attain elevations greater than 10,000 feet.

The Snake River plains in this region are underlain by basalt covered in some places to a considerable extent by soil that has largely been deposited by the wind, alluvium and stream gravel, and drifting sand or dunes. Elsewhere the somber basalt forms the surface in large or small exposures, locally rough with low broken ridges, and elsewhere with low, relatively smooth, dark surfaces marked by polygonal cracks. Over considerable areas the thin, grass-covered soil, with intervening dark ledges, resembles in the fall the surface of a yellowish sea with black waves. Bold cliffs of black basalt with columnar aspect border the principal stream valleys and in places, as in the lower canyon of Snake River, form high canyon walls. The old broken cone and crater of Sand Mountain, near St. Anthony, with the adjacent group of sand dunes, are conspicuous topographic features. Elsewhere volcanic cones with craters rise above the surface of the plain. Some of them consist of basaltic débris, but others, notably Big and East buttes, northwest of Blackfoot, are composed of rhyolite and stand as volcanic islands in the basaltic sea.

The drainage of the region south of the Continental Divide is all gathered by Snake River and delivered through Columbia River to the Pacific Ocean. North of the Continental Divide are the head-

waters of the Missouri. The mountains have many springs and permanent streams which on the Idaho side supply the two forks of Snake River and their larger tributaries, such as Blackfoot River, Willow Creek, and Teton River.

In the vicinity of the mountains these streams are rather closely spaced and water for camping or other purposes is available at numerous places along the roads. In the bench lands underlain by lava, however, the permanent streams are much farther apart and water may be had at comparatively few places. On the road from Teton to St. Anthony, a distance of about 30 miles, Canyon Creek is practically the only watering place between the two crossings of Teton River, some 24 miles apart. Ranchers who occupy dry farms on these benches must sink wells through the lava perhaps 200 feet or more until a suitable supply of water is reached, or haul it for long distances. The water wagon and water barrel are familiar sights throughout the dry-farm district.

The low alluvial lands adjoining Snake River and the lower courses of its tributaries are supplied with water by means of irrigating ditches, some of which are themselves large-sized creeks. Northwest of Snake River the Continental Divide is also well supplied with permanent streams, but most of the surface drainage sinks through the porous and shattered lava so that comparatively little reaches the river directly, though much is doubtless supplied by springs. On the direct road from St. Anthony to Kilgore, a distance of approximately 30 miles, no water is seen after leaving the ditch a mile north of Parker until Camas Creek, at the lower end of Camas Meadows, is reached, some 25 miles beyond.

INDUSTRIES.

The alluvium along Snake River and some of the larger creeks at elevations of 4,500 to 5,000 feet furnishes considerable areas that are suitable for irrigated fields, which produce a variety of valuable crops. Locally these lands are subject to local frosts or are too wet for cultivation but yield abundant crops of hay and support large numbers of cattle. All the larger soil areas, whether irrigable or not, are being rapidly taken up for cultivation, and forlorn homesteads are even perched here and there among the lava ledges where only a few square rods or acres of cultivable soil is available. Owing to the scarcity of water, much of the lava country must remain waste until through a system of wells or otherwise water is furnished for stock and for domestic use.

The mountains are heavily timbered with aspen, red fir, and other conifers, which yield local supplies of fuel and building material. Several sawmills supply the demand for rough lumber, but dressed

lumber is largely shipped in by rail. The mountains also, through the grazing regulations of the United States Forest Service, are made available for the summer pasturage of large numbers of sheep and cattle.

Coal is mined in the Horseshoe district of Teton Basin. The coal beds and their development are described on pages 137-145.

St. Anthony and Idaho Falls, the two principal cities in the district, owe their location to the presence of falls where Snake River has cut through the alluvium and plunges over basaltic ledges, and Blackfoot, just to the southwest, is located favorably at the confluence of Snake and Blackfoot rivers. All three cities are railway junction points and distributing centers for the increasingly important agricultural products of the region.

Many details regarding the settlements, industries, scenery, and general geology of the district are given in the guidebook of the Overland Route published by the Geological Survey.*

GEOLOGY.

SEDIMENTARY ROCKS.

The sedimentary rocks of the region have a wide range both in character and in geologic age. All the great geologic periods from early Carboniferous to the present are represented. In southeastern Idaho these rocks have been subdivided into many formations, which are rather fully described in some of the published accounts of that region.⁴ They are summarized in the accompanying table, which is given for reference. Some of the formations that occur in the southern part of southeastern Idaho were not recognized here, and others were not differentiated. An additional column has therefore been placed in the table to show the units mapped.

The Phosphoria formation deserves brief description because it has been prospected and mined for coal at several places in the region here described. The formation occurs in many bands distributed through the mountain ranges. (See Pl. XV.) The phosphatic shale

* Lee, W. T., Stone, R. W., Gale, H. S., and others, Guidebook of the western United States, Part B, The Overland Route: U. S. Geol. Survey Bull. 612, pp. 130-147, 1915.

⁴ Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430, pp. 457-535, 1910.

Richards, R. W., and Mansfield, G. R., Preliminary report on a portion of the Idaho phosphate reserve: U. S. Geol. Survey Bull. 470, pp. 371-489, 1911.

Schultz, A. R., and Richards, R. W., A geologic reconnaissance in southeastern Idaho: U. S. Geol. Survey Bull. 530, pp. 267-284, 1912.

Richards, R. W., and Mansfield, G. R., Geology of the phosphate deposits northeast of Georgetown, Idaho: U. S. Geol. Survey Bull. 577, 1914.

Mansfield, G. R., and Roundy, P. V., Revision of the Beckwith and Bear River formations of southeastern Idaho: U. S. Geol. Survey Prof. Paper 98, pp. 75-84, 1916.

Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713 (in press).

Northern part.

System.	Thickness (feet).	Remarks.
Quaternary.		
Unconformity		
Tertiary.	PH 600+	Chiefly conglomerate, probably also rhyolite and basalt. Age undetermined.
Unconformity	Ec	
Cretaceous.	Up 0,800	Light-colored sandstone and clay aggregating 5,800± feet, with coal beds and some calcareous beds tentatively correlated with the Frontier and Aspen formations of southwestern Wyoming.
		Dark-colored sandstone and shale with some calcareous beds, aggregating 5,000 feet; typical Bear River (basal Upper Cretaceous) fossils.
Unconformity	Lo	
Cretaceous (?).	1,300+	Not differentiated; conglomerate much reduced in topographic prominence and thickness.
Jurassic.	1,500	Formations recognized but not differentiated.
	800	
Triassic (?).		Not definitely recognized.
	1,400	
Triassic.	Lo	Recognized but not differentiated.
		Not definitely recognized.
	Pe 350	Locally the phosphatic shale of the Phosphoria formation yields a little petroleum when distilled, is black and shiny, and is mistaken for coal. Rex chert member well developed but without limestone; quartzite in upper part.
Carboniferous.	Pe 4,400+	Not differentiated.
	Mis	

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member is distinctly nodular or even conglomeratic at the base, and there is a bed of hard phosphate a foot or more thick that is somewhat siliceous and furnishes large float fragments with the characteristic bluish-white bloom. The main phosphate beds lie above this bed and are dark colored, locally coaly black, and yield upon distillation a little petroleum. The characteristic oolitic texture, however, may be clearly distinguished, the tiny rounded grains or oolites being readily visible to the naked eye. The disturbance that the shale has undergone in assuming its usual inclined position has made it shiny and smooth in some places so that it might readily be mistaken for coal. The thickness of the phosphatic shale, where exposed in Palisade Creek, is estimated at more than 100 feet.

The coal of the region occurs in formations known or supposed to be of Cretaceous age. Some of it is hardly more than carbonaceous or lignitic shale. Several of these formations were recognized but are not differentiated on the map. The lowest corresponds with the Gannett group (Cretaceous ?) and Wayan formation (Cretaceous) of southeastern Idaho. There is a distinctive dark conglomerate about 25 feet thick at the base, composed chiefly of chert pebbles. Above this are variegated beds with some limestones, succeeded by yellowish and dark-grayish sandstones with interbedded carbonaceous shale, the whole aggregating about 1,300 feet in thickness.

The second formation consists of dark-grayish sandstone and shale, with carbonaceous shale and some calcareous beds aggregating perhaps 5,000 feet in thickness. Typical Bear River fossils have been found in it at a number of places, but there is uncertainty about the position of the upper and lower limits of the formation.

Above the beds assigned to the Bear River is gray clay of undetermined thickness which may correspond with the Aspen formation of southwestern Wyoming. Above this are generally light-gray sandstone and clay, with some coal beds, which together with the underlying clay apparently aggregate more than 5,800 feet in thickness if there is no duplication. There is a suggestion, however, as shown in figure 12 (A), that the coal beds in the Horseshoe district may be folded into a syncline. If they are, the thickness is only 3,600 feet.

Fossil invertebrates and leaves have been found in these beds. The invertebrates were collected from calcareous beds at the Brown Bear mine. T. W. Stanton states that they probably belong to the fauna of the Colorado group and may have come from the Frontier formation. An earlier determination of perhaps more scanty material from the same locality gave the age as that of the younger Mesaverde formation (of the Montana group) of the Rock Springs district, or the Adaville formation of southwestern Wyoming.⁵

⁵ Woodruff, E. G., The Horseshoe Creek district of the Teton Basin coal field, Fremont County, Idaho: U. S. Geol. Survey Bull. 541, p. 382, 1914.

The evidence of the fossil leaves collected in the Horseshoe field and on the Continental Divide in T. 14 N., R. 38 E., as determined by F. H. Knowlton, is equally inconclusive. The field relations and lithology favor Frontier rather than Mesaverde age, and the beds are tentatively so referred. This provisional assignment is in accord with the views of A. R. Schultz,* who is familiar with the formations at Rock Springs and Adaville, Wyo., and in the Horseshoe district of Idaho.

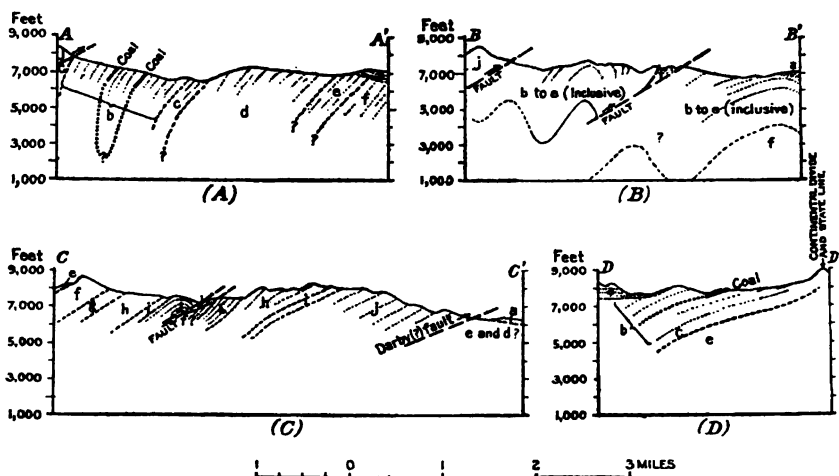


FIGURE 12. Geologic structure sections of parts of the Horseshoe, Teton Basin, and Continental Divide districts, Idaho. *A*, Section across the Horseshoe district in the vicinity of the Brown Bear and Boise mines; *B*, section in the region of the Horseshoe Creek-Mahogany Creek divide; *C*, section along the divide between Mahogany Creek and Paterson and Henderson creeks; *D*, section across Cottonwood Creek, Continental Divide district, in the vicinity of the Scott & Bucy mine. *a*, Lava and conglomerate; *b*, Frontier (?); *c*, Aspen (?); *d*, Bear River; *e*, Wayan formation (?) and Gannett group; *f*, Stump sandstone, Preuss sandstone, and Twin Creek limestone; *g*, Nugget sandstone to Thaynes group; *h*, Thaynes group and Woodside formation; *i*, Phosphoria formation; *j*, Wells, Brasier, and Madison (?) formations.

The occurrence of clay in the supposed Frontier formation gives rise to frequent landslides.

The other formations of the region are sufficiently described for the purposes of this report in the preceding table.

GENERAL STRUCTURE.

Three broad structural areas may be distinguished in the general region—(1) the mountains of the southeastern part; (2) the Snake River plains, occupying the great central portion; and (3) the Continental Divide, on the north. The first and third areas are composed largely of sedimentary rocks that have been deformed to a greater or less extent by folding and faulting. This is particularly

* Personal communication.

true of the southeastern area, where the structural features represent the northwestward continuation of great folds or faults, some of which extend many miles to the southeast. The dominant faults of the region appear to be northeastward overthrusts. The names applied to faults on the maps indicate their supposed relation to well-known faults farther southeast. The folds are generally open and upright, but a certain tendency to overturning may be noted. The inferred details of structure in the sedimentary areas are shown on the accompanying maps and geologic structure sections.

Little attention was paid in the present examination to the structure of the Snake River plains. Locally near the margins, as in the Willow Creek district, sedimentary rocks exposed through the removal of the lavas by erosion indicate the continuation of the folded and faulted sedimentary rocks beneath the lavas. The lavas that underlie the plains have been built up by a succession of practically horizontal flows, between which at certain places there were intervals of time sufficient for the deposition of alluvial or lake deposits or for the formation of soils. Along the canyon walls of Snake River and in wells at various places the composite nature of the lava series is revealed. A well sunk in the lava several miles east of Teton passed through a number of layers of soil between beds of basalt and rhyolite. One bed of soil was encountered at a depth of 400 feet.⁷

COAL BEDS.

GENERAL OCCURRENCE AND CHARACTER.

Coal occurs at a few places in eastern Idaho in two or perhaps three of the Cretaceous formations. It is definitely known to be associated with the Bear River formation and with less certainty is believed to occur also in the Wayan formation. In neither of these formations is it of commercial value. Better coal is found in a higher formation, thought to be the Frontier, though the paleontologic evidence of its age is not entirely conclusive. The distribution of the Cretaceous strata is shown in Plate XIV and the inferred position of the workable coal beds is indicated in Plate XV and figure 13.

The coal of the Wayan (?) and Bear River formations is hardly more than carbonaceous shale in which the carbon is locally abundant enough to burn. The moisture and ash are high and the heating value is low, as shown by the analysis of a sample from Pine Creek Pass, No. 29280 in the table on page 152. (See also section 1, fig. 14.) The coals of the Willow Creek-Caribou and Pine Creek districts are of this class.

⁷ Lee, W. T., Stone, R. W., Gale, H. S., and others, op. cit., p. 139.

The coal of the Frontier(?) formation in this region, however, is of bituminous rank, fairly pure, and of relatively high heating value. The areas of known commercial coal are not sufficiently large and the beds are not thick enough to be worked on any great scale. Even if the mines were fully developed they would probably not supply the local demand, at present prices. They are grouped in two districts—the Horseshoe district, in Tps. 4 and 5 N., Rs. 43 and 44 E., and the

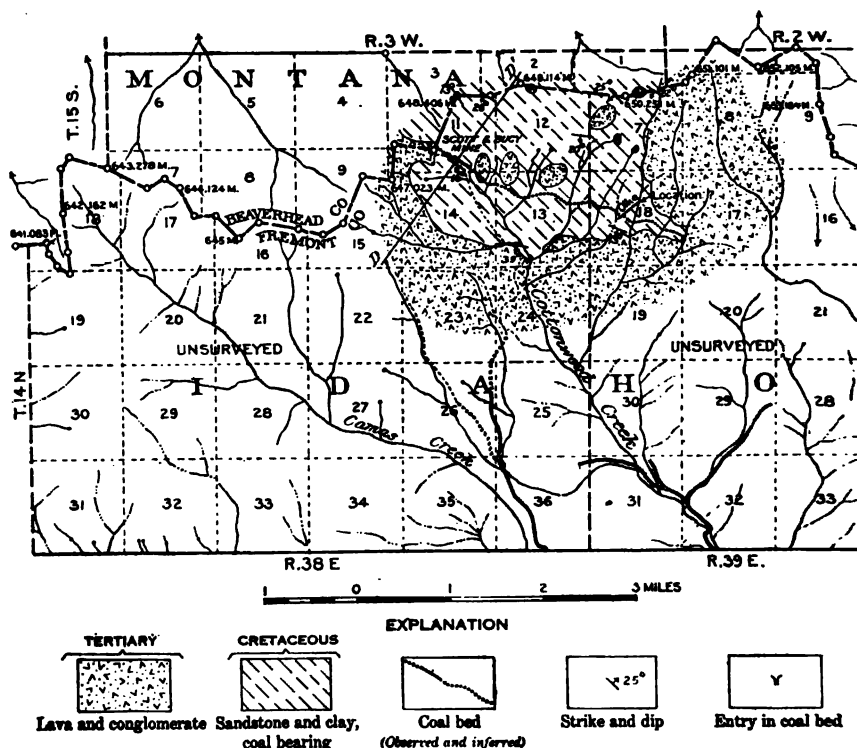


FIGURE 18.—Geologic map of part of the Continental Divide district, on Cottonwood Creek, in unsurveyed T. 14 N., Rs. 88 and 89 E., Idaho.

Cottonwood Creek district, in T. 14 N., Rs. 38 and 39 E., on the Continental Divide. The Horseshoe district has been productive for several years, but the other district is not yet developed.

WILLOW CREEK-CARIBOU DISTRICT.

Cloward entry.—In the SE. $\frac{1}{4}$ sec. 6, T. 1 N., R. 40 E., on the hill slope a few rods back of the house of J. A. Cloward, is an entry that was opened in the winter of 1916. It is about 100 feet long and trends about N. 50° E., curving slightly toward the south. The "coal" consists of the more carbonaceous portions of earthy and carbonaceous shaly lenses that wedge in and out and have a white

powdery substance in the partings. Nine layers were counted at one place, ranging in thickness from about one-sixteenth of an inch to 18 inches. It is doubtful, however, if enough fuel of this character can be obtained for local needs without involving prohibitive expense.

Brinson mine.—The Brinson mine, in the NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 34, T. 2 N., R. 40 E., is probably the property described by Schultz* as the Miller mine. A man named Miller is reported to have been associated with Mr. Brinson. According to Schultz, work was begun at the Miller mine in 1900 by the Canyon Coal Mining Co., which constructed a shaft, tunnel, road, and buildings, and installed machinery, the whole at a cost reported at \$6,000. In 1910 Mr. Miller, one of the members of the former company, filed application to purchase and was permitted to make payment for 160 acres of coal land at \$10 an acre. Work was continued. A shaft 40 feet deep was sunk and an engine and hoisting machinery were installed at an additional cost of about \$2,500. The developments just described tally well with those seen at the Brinson mine, which is the only mine known to such residents of the vicinity as the writer was able to consult.

The tunnel is about 115 feet long and trends N. 76° E. at the entrance. About 61 feet from the portal is a shaft in nearly vertical carbonaceous and gypsiferous shale 7 feet 6 inches thick, the so-called coal bed. Two other coaly layers 6 inches and 11 inches thick, respectively, were noted. As in Cloward's prospect, the shale is probably carbonaceous enough in places to burn, and such material is reported to be excellent for blacksmithing. At the time of the writer's visit the shaft was largely filled with water and the exposed parts of the shale were intensely sheared and weathered. The shaft is reported to end in gravel like stream gravel. A fault by which conglomerate beds were brought against the shale might give rise to such a report and is not improbable. No coal of promising appearance was seen. Several other prospects occur in the vicinity.

The road, which is cut in the steep and rocky canyon wall at a uniform grade for nearly a mile, is now out of repair, and it is evident that no recent work has been done at the mine. No reports are available regarding the amount of coal extracted from this mine, but from the character of the so-called vein it is clearly negligible and the prospects of successful development are slight.

Croley mine.—The carbonaceous shale of the Wayan (?) formation along Grays Lake Outlet has been prospected here and there for coal. Perhaps the most extensive development is the so-called Croley mine, in the SE. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 27, T. 1 S., R. 41 E. The workings

* Schultz, A. B., A geological reconnaissance for phosphate and coal in southeastern Idaho and western Wyoming: U. S. Geol. Survey Bull. 680, p. 74, 1918.

consist of two caved tunnels and several prospects. The bed can not now be seen, but according to one report it is 8 inches thick, and according to another 18 inches thick. It was stated that material was obtained that would burn, but it crumbled and would not form lumps. Fragments of dark shale and of carbonaceous matter, somewhat lignitic in character, were seen on the dumps.

Another prospect, known to some as Croley's mine, is reported farther down the valley in the northeast face of Pine Mountain, opposite a small island in Grays Lake Outlet and on the south side. This prospect was not found in the time available for search. It may perhaps be the one indicated as the Croley mine by Schultz and Richards on their map and shown as a coal tunnel in the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 24, on the plat of T. 1 S., R. 40 E. The structural relations of the region suggest that it lies on the strike of the beds already described. Unless unsuspected faults intervene it is clearly in the same formation.

Fall Creek basin and Heise.—The coal prospects of the Fall Creek and Heise districts are in carbonaceous shale that contains lignitic material and is of either Wayan or Bear River age.

PINE CREEK DISTRICT.

Pine Creek Pass.—The old prospect at Pine Creek Pass, approximately in the SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 24, T. 3 N., R. 44 E.* (unsurveyed), was reopened in September, 1917, by John Nocker and an associate, of Kemmerer, Wyo. At the time of the writer's examination the slope excavated on the dip of the coal bed had been cleared to a depth of about 15 feet from the surface. A tiny fault was noted. The following section was measured at a depth of 12 feet:

Section of coal bed at Pine Creek Pass prospect.

	Ft. in.
Limestone, dark; Bear River fossils.....	8+
Clay, sandy and rusty.....	6±
Coal, mashed, slickensided.....	1 10
Clay, dark, sheared.	

The coal bed strikes N. 55° W. and dips 55° SW. About 2 feet higher along the dip the thickness of the bed is 2 feet. The coal apparently contains much clay, for when moist it becomes plastic. A sample from the place measured was analyzed with the results indicated in the table on page 152 (analysis 29280). The section is graphically shown in figure 14. The content of moisture and ash is high, and the heating value (7,376 British thermal units for the air-dried sample) is below the minimum allowed (8,000 British thermal

* Schultz, A. R., A geologic reconnaissance for phosphate and coal in southeastern Idaho and western Wyoming: U. S. Geol. Survey Bull. 680, p. 74, 1913.

units) for workable coal according to present rules of the United States Geological Survey for coal-land classification.¹⁰

Kunz drift.—About a mile east of Pine Creek Pass, on the north side of the road, is a caved drift in Bear River carbonaceous shale. The writer is indebted to Mr. Joseph Kunz, of Victor, Idaho, for the following data regarding it. This drift was driven about four years ago by Samuel and Joseph Kunz and their associates. The "coal" occurs in a 6-foot bed, channeled with boulders and gravel, lying above a black clay and below a limestone which is sugary just above the coal but hard farther above.

The writer's examination showed a black shale with carbonaceous lenses. Several lenses, ranging in thickness from 2 to 8 inches, were noted, and above them lay a black fossiliferous limestone. The rocks at this prospect appear to be near the axial region of a subordinate

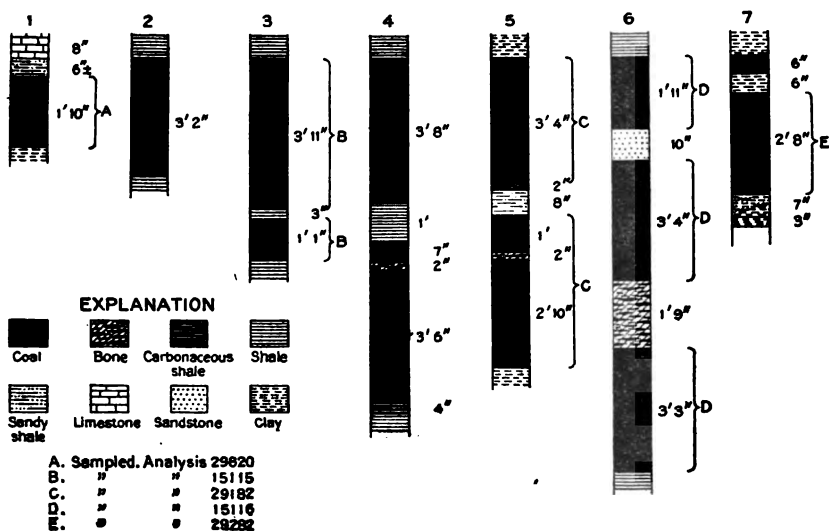


FIGURE 14.—Coal sections in the Pine Creek and Teton Basin districts and at Cottonwood Creek in the Continental Divide district, Idaho. 1, Pine Creek Pass; 2, Boise mine; 3, Brown Bear mine; 4, Woodruff's locality 10; 5, Belicut mine; 6, Horseshoe mine; 7, Scott & Bucy mine.

fold and to strike N. 84° E. and dip 19° N. The stratigraphic relations suggest that this is the same bed as the one exposed at Pine Creek Pass. The greater thickness of coal noted by Mr. Kunz may be in part due to the location of the bed in the fold or to irregularity of the bed.

Other prospects.—About 1,000 feet west of the Kunz prospect, and on the south side of the road, is another caved drift opened by the

¹⁰ Emith, G. O., and others, The classification of the public lands: U. S. Geol. Survey Bull. 537, p. 96, 1913.

same prospectors. The caving is so complete that only fine dark shale fragments are to be seen. In a neighboring canyon south of the Pine Creek road other coal prospects are reported. A cabin and one or two openings so badly caved as to be scarcely recognizable were all that were found.

RAINY CREEK.

Southeast of Pine Creek the rocks of the Cretaceous basin continue across Rainy Creek. About 100 yards southwest of the point where the trail from Pine Creek to Fogg Hill crosses Rainy Creek there is a group of coal prospects. Two of the prospects occur on the same bed at different heights, and the third is a tunnel about 100 feet west. The bed at Rainy Creek has been locally reported as 10 feet thick, but this appears to be an error. The bed in which the first two prospects are made is a dark shale with a carbonaceous stratum about 7 feet thick. The footwall at the entrance of the lower prospect, a caved drift, is a gray sandstone which strikes N. 64° W. and dips 66° E., and the hanging wall is a black shale. No coal was exposed, but some fine carbonaceous matter lay distributed through the dump. No fossils were seen. The upper opening was also caved. According to A. E. Harris, of Rexburg, Idaho, who is familiar with much of this region, the prospector who dug the main drift struck a fault and stopped. He then started a tunnel, the third prospect above mentioned, and after digging a short distance ran into his previous working and stopped again. The tunnel is now caved.

East of the coal prospects and over the hill between the forks of the creek the Fogg Hill trail descends a long point on which a fossiliferous ledge of brownish-gray limestone occurs. Fossils were collected from this ledge, among which species of *Ostrea* and *Modiola* were identified by T. W. Stanton, who states that they may have come from the Bear River formation, though he thinks it more probable that they came from the Frontier formation. The stratigraphic relations appear to favor the Bear River rather than the Frontier formation, but it is possible that a small local syncline of the Frontier is present.

PALISADE CREEK.

Reports from several sources of a fine natural exposure of coal in Palisade Canyon led to the extension of the reconnaissance to that exposure. No difficulty was experienced in reaching it, and there is no doubt of the identity of the locality visited with that of the reports. About a mile below the forks of the creek a black, coal-looking rock extends along the south side for perhaps 100 feet and rises abruptly from the water for 40 or 50 feet. The beds are vertical and strike N. 55° W., and their smutty and shiny surfaces are certainly suggestive of coal. A closer examination, however, re-

veals the oolitic texture of phosphate rock, which, with interbedded shale and black, fetid limestones, makes up the exposure. The phosphate rock is part of the Phosphoria formation, which here lies along the west side of a fault between Carboniferous formations and Jurassic limestone. The line of the fault is marked by small canyons that extend northwest and southeast from the main creek. This is probably the same fault that separates the Cretaceous and Carboniferous rocks in Pine Creek. Palisade Canyon was not traversed above the Fogg Hill trail, but there seems little reason to suppose that Cretaceous rocks or coal beds occur there.

BURNS CANYON.

The General Land Office plat for T. 4 N., R. 43 E., shows indications of coal in sec. 2 and near the southwest corner of sec. 19. The locality in sec. 2 is in Carboniferous rocks and was not visited. The locality in sec. 19 is in Coal Mine Canyon, a tributary of Burns Canyon, and is reported to have produced "coal that would burn." This mine was visited. It lies near the head of the canyon, in the phosphatic shale of the Phosphoria formation, like the fine natural exposure in Palisade Creek. Masses of phosphate rock, black, smutty, glossy from rock shearing, and superficially resembling coal, lie scattered on the dump, but the characteristic oolitic texture of the phosphate is readily seen, and on some pieces the bluish-white bloom may be detected.

TETON BASIN.

HORSESHOE DISTRICT.

The coal deposits of the Horseshoe district have been described by Woodruff,¹¹ who gives details of the mines and prospects, including analyses and sections, some of which are reproduced in the table on page 152 and in figure 14. The Horseshoe district, which is the only producing coal field in eastern Idaho, lies on the west side of Teton Basin and includes portions of Tps. 4 and 5 N., Rs. 43 and 44 E. (See Pl. XV.) The district as a whole may be considered as including all the Cretaceous rocks with their intervening formations north of the line of Mahogany Creek, an area of nearly 20 square miles. The part that carries coal beds that can be profitably mined, however, is much smaller and probably does not exceed 3 or 4 square miles. The distribution of the formations of the district is shown on the map, and the general structure of the coal-bearing portion as here interpreted is shown in the geologic structure section, figure 12 (A).

¹¹ Woodruff, E. G., The Horseshoe Creek district of the Teton Basin coal field, Fremont County, Idaho: U. S. Geol. Survey Bull. 541, pp. 370-388, 1914.

STRUCTURAL FEATURES.

The fault along the west side of the Cretaceous area is here considered a thrust rather than a normal fault, as shown by Woodruff. In the line of the section given in figure 12 (A) it would be difficult and perhaps even impossible to discriminate between normal and thrust faults by inspection. Great overthrusts are, however, more characteristic of southeastern Idaho and western Wyoming than great normal faults. Notable overthrusting has also taken place in this region, as is well illustrated by the little Carboniferous outlier on the Cretaceous rocks of secs. 10 and 15, T. 4 N., R. 44 E. According to Schultz¹² the parallel normal fault farther west shown by Woodruff is not evident in a traverse along the line of structure section A-A' but may represent a subordinate strike fault more clearly shown at its junction with the main thrust. Such a fault would be difficult to detect in beds similar on both sides.

The rocks east of the coal-bearing beds as mapped by Woodruff are not Paleozoic, as he suggests, but belong to lower portions of the Cretaceous, as shown by the characteristic Bear River fauna from sec. 19, T. 5 N., R. 44 E. Similarly the supposed Paleozoic ledges in sec. 32, T. 5 N., R. 44 E., are Jurassic or Cretaceous. The fault in the eastern part of the district as mapped by Woodruff may be present, but as the strata west of it are not Paleozoic his argument for it¹³ has little weight. Several minor cross faults occur in the Cretaceous, as noted by Woodruff, but no strike faults were recognized in the rocks of that age north of Horseshoe Creek. Such faults might be present and easily escape detection because of the lithologic similarity of the beds.

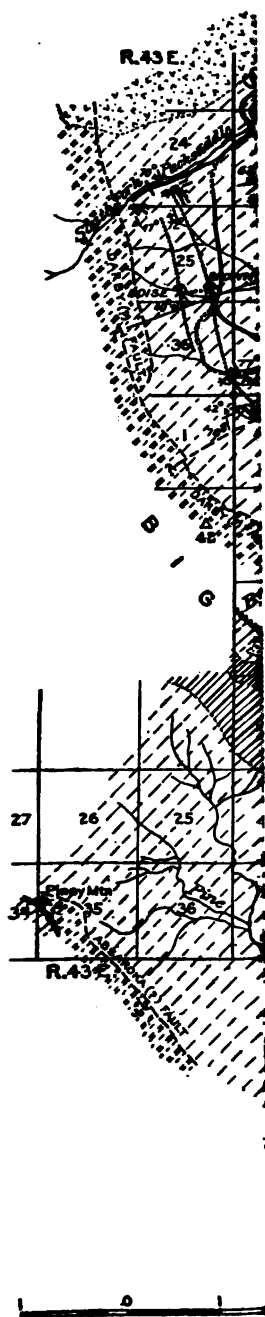
The structure south of the general line of Horseshoe Creek differs considerably from that to the north. The Jurassic ledges that form the backbone of the ridge east of the south fork of the creek terminate abruptly south of the main creek. The productive coal beds also have not been traced much south of the Horseshoe mine in the northeast corner of T. 4 N., R. 44 E. This may be due to the extensive mantle of débris composed of older rocks, but there are numerous gullies in which such beds might be exposed. Because of these differences a normal fault with downthrow to the north is tentatively drawn south of the Horseshoe mine and of the main creek, although other considerations, which can not be entered upon here, indicate that such a fault may not be required.

The generally troughlike structure east of the great thrust fault, and clearly shown at the south end of the district, has an important economic bearing, for it leads to the suggestion that the two coal beds mapped by Woodruff may in reality be the same bed caught in a

¹² Schultz, A. R., personal communication.

¹³ Woodruff, E. G., op. cit., p. 383.

U. S. GEOLOGICAL SURVEY



GEOLOGIC MAP

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rather closely folded syncline of which the two beds would represent the opposite limbs, as indicated with a query in structure section A-A'. Such a structure would naturally limit the depth to which the coal could be worked, even if no other limiting factors were involved. Certain differences in the coal beds at the Boise, Brown Bear, Bellcut, and Horseshoe mines seem at first sight to oppose the synclinal suggestion, but they may not be so serious as to disprove it. For example, the section at the Bellcut mine (probably Woodruff's locality 10) shows 7 feet 4 inches of coal with a parting of sandy clay 10 inches thick near the middle. A similar sandy clay bed occurs in the coal bed 10 feet 3 inches thick at the Horseshoe mine but nearer the top. It is thought by Woodruff and by L. Hillman, manager of the mine at the time of the writer's visit, that the bed at these two localities is the same. The bed at the Brown Bear mine ranges from 4 feet 5 inches to 5 feet 3 inches in thickness, and the bed at the Boise mine is only 3 feet 2 inches thick. These beds do not show the sandy clay bed. The Brown Bear bed contains a thin layer of shale and the Boise bed is clear coal. Available analyses of the coals from Brown Bear, Bellcut, and Horseshoe mines show considerable similarity in the quality of the coal. Clay and shale beds are generally lenticular, though at many places attenuated, and may be expected to thicken, thin, or disappear even if the strata suffer no deformation.

If the coal beds are parts of a closely folded syncline they would be likely to vary in thickness with their location in the fold. Parts of the bed nearer the axial region or bottom of the trough would be thicker than parts of the bed on the limbs or sides. The thickness of the portions on the limbs would vary with the amount and character of the shearing stresses developed during the deformation of the rocks. These stresses would also cause the thinning or disappearance of clay or shale beds on the limbs of the fold and their thickening in the axial region. The same stresses would also develop throughout the coal lines of cleavage or parting which would cause it to break easily or crumble when extracted. The crumbling of the coal is one of the disadvantageous features in mining in this field.

In a northward-pitching syncline the axial portion with thicker beds would be exposed at the south end. The Horseshoe mine with the thickest beds of the district is so located. Farther north the axial region would be deeper and the exposed portions would lie along the limbs where the beds are thinner. If the axial plane of the syncline were tilted or bent, as suggested in the structure section, the exposed portions of the limbs would not be symmetrically located with reference to the axial plane and might be expected to differ

somewhat in character and thickness. These reasons seem sufficient to account for the differences noted in the coal bed at the different mines. The hypothesis of synclinal structure of the coal bed appears to be supported by such facts as are available, but owing to the heavy cover of *débris* and the thick growth of vegetation in the region where the bed should be exposed, confirmation of this hypothesis must await more extended exposure of the strata by mining operations.

At the westernmost opening of the Horseshoe mine the slope follows the dip of the sandstone, about 33° NW. About 100 yards west of this slope is a broad ledge of massive sandstone, whose attitude is obscure but which seems to strike N. 55° E. and dip about 10° NW. These exposures appear to be near the axis of the supposed syncline, and give suggestions of its pitch. On the assumption of the steeper dip, which seems justified by the somewhat steeper dip given by Woodruff for a locality near by, the bottom of the synclinal coal bed at the Brown Bear and Boise mines should lie about 4,800 feet below the surface, as indicated in figure 12 (A). On the assumption of the 10° dip, it should lie about 1,200 feet below the surface. The dip of the bed at the Belicut mine, 70° , suggests that the dip steepens down the limbs of the fold, as shown in the structure section.

The structure of the southeastern part of the Horseshoe district is apparently anticlinal, with the axis near the western edge of the lava and largely concealed by it. The rock between the Jurassic beds and the lava along the line of the structure section *B-B'*, in figure 12, is Cretaceous sandstone, rather poorly exposed but apparently dipping southwest. The southeast face of the prominent lava-capped hill in the southeast corner of sec. 33 gives an excellent exposure of the sandstone with a northeasterly dip of 21° . The stratigraphic position of the sandstone is not known, but it is assumed to be possibly of Bear River age. No fossils were found in it.

CHARACTER OF THE COAL.

Woodruff states that the coal is bituminous and rather free from impurities but is noncoking according to the agate-mortar test. A large part of the coal breaks down to fine fragments. It is thus not adapted to long-distance transportation.

OWNERSHIP.

The properties recently consolidated under the name Teton Valley Coal Co. were transferred in December, 1917, to mineral operators from Seattle and Spokane.¹³

¹³ Bell, R. N., Nineteenth annual report of the mining industry of Idaho, for the year 1917, p. 101.

COAL BEDS.

According to Bell ¹⁴ 20 beds ranging in thickness from 6 inches to 10 feet have been identified by surface work throughout a linear extent of 2 miles, and three of these beds have been rather extensively developed. The number of beds present can only be conjectured until much underground work has been done and a detailed knowledge of the structure obtained. The beds can not well be traced at the surface because of the thick cover of rock débris and vegetation. There may be as many as 20 beds or even more, but practically all of those prospected, except the beds on which the four mines described below are located, have given little or no promise of commercial value. Probably some of the openings now regarded as exposures of distinct beds may prove to be on the same bed. There seems little doubt that the Horseshoe and Bellcut mines are so located. On page 139 reasons are given for thinking that the Brown Bear and Boise mines may be on the same bed as the Horseshoe and Bellcut mines.

MINES.

Brown Bear mine.—The coal bed at the Brown Bear mine varies somewhat in thickness and character, as shown by the following sections measured by Woodruff, who also recognized and mapped several faults in the coal bed:

Sections of coal bed in Brown Bear mine.

North end of mine.			South end of mine.		
Shale. ¹⁵	Ft.	in.	Shale.	Ft.	in.
Coal ¹⁶	3	11	Coal.....	2	10
Shale.....		3	Coal, crushed	1	7
Coal ¹⁶	1	1	Shale.		

The general plan of the Brown Bear mine comprises a horizontal crosscut tunnel 325 feet long with drifts and stopes north and south along the coal bed. The south drift, which is about 800 feet long, has caved. The north drift is 1,700 feet long. Further extension in that direction is unprofitable both because of the cost of handling the material by present methods and because of the deterioration of the coal by the northward thickening of a parting.

In August, 1917, work was undertaken to extend an inclined air shaft, then 80 feet deep on the dip of the coal bed, 44°, to a depth of 200 feet below the surface. This shaft was to be used for hoisting the coal from stopes at the new level. A hoist, track, and car of about 1-ton capacity were to be installed. According to Bell ¹⁶ the

¹⁴ Bell, R. N., op. cit., p. 103.

¹⁵ See analysis No. 15115 (p. 152), and also section 3, fig. 14.

¹⁶ Bell, R. N., op. cit., pp. 101-104.

shaft was sunk to a depth of 250 feet by the former owners and extended to 400 feet by the present owners, who plan to extend it to the 500-foot level. The owners also plan a crosscut tunnel 5,000 feet long, which will afford natural ventilation, drainage, and means of handling the coal by gravity. It is claimed that 4,000,000 tons of coal is available above the 500-foot level, but no statement is made regarding the basis of the estimate. A spur track to the mine from the Oregon Short Line Railroad and equipment to handle 500 tons a day are among the plans for future development.

Water is rather abundant in the mine and will require pumping until the crosscut tunnel is completed. Before the deepening of the shaft it was removed by gravity along the tunnel.

Horseshoe mine.—The coal bed at the Horseshoe mine is thicker than at any other recorded locality in the district, and the heating value of the coal is relatively high. The following section was measured by Woodruff:

<i>Section of coal bed in the Horseshoe mine.</i>		Ft. in.
Shale. ²⁷		
Coal	1	11
Sandstone		10
Coal, ²⁷ crushed	3	4
Coal, bony	1	9
Coal, ²⁷ crushed	3	3
Shale.		

This mine, which consists of a single entry 500 feet long, is badly caved but can still be entered for a distance of about 200 feet. An attempt was made in the winter of 1916 to reopen the mine, and a small amount of coal was extracted. The attempt was abandoned on account of the unsatisfactory condition of the old workings.

Bellcut mine.—The Bellcut is a new mine opened in the fall of 1916 in what is probably Woodruff's locality 10. The workings consist of an open cut perhaps 100 feet long leading to a crosscut tunnel 30 feet long to the coal bed. Drifts extend north and south 170 and 315 feet, respectively, each timbered to the end. The north drift is very wet. The coal at the face is crushed fine, forming mud that has slumped forward at least 10 feet into the drift. The miners are said to have struck a fault here. The south drift is fairly dry. The coal at the face is hard and breaks unevenly without any special tendency to follow bedding planes. The dip of the bed is 70° W. The following section was measured at the south face:

²⁷ See analysis 15116 (p. 152), and section 6, fig. 14.

Section of coal bed at Bellcut mine.

	Ft. in.
Clay, slickensided.	
Coal, hard-----	3 4
Bone -----	2
Clay, sandy, gray-----	8
Coal, ²⁸ including 2-inch bone irregularly distributed about 1 foot from top-----	4 0
Clay, slickensided-----	8 2

At the portal the coal-bearing formation is exposed for about 45 feet along the open cut, showing buff-colored sandstone and clay with dark shale, much weathered and somewhat carbonaceous.

About 100 feet up the gully above the Bellcut mine a 20-inch bed of poor coal, much weathered, is exposed in the north bank. About 200 yards above the mine in the same gully is a bed 22 inches thick, said by Mr. Hillman to be good coal for blacksmithing. The bed strikes N. 33° W. and dips 69° W. It was too thoroughly weathered for sampling. Streaks of iron-stained clay were seen in it but no parting or bone. The hanging and foot walls are both clay.

Boise mine.—The coal bed at the Boise mine is 38 inches thick, without bone or parting, and lies between beds of shale. (See section 2, fig. 14.) Unfortunately it has caved so that further production is delayed or perhaps even prevented.

PRICES AND PRODUCTION.

The coal from the Bellcut mine was sold in the winter of 1916 as run of mine coal at \$1.50 a ton at the mine. The lump coal from the Brown Bear mine brought \$4.50 a ton at the mine during the same season. The fine coal on the dumps at the Brown Bear was selling in the summer of 1917 for \$1 a ton at the mine.

The production has always been small, a few tons a day. The total production in 14 years, including the output of the Horseshoe mine, amounted, according to Mr. Hillman (August, 1917), to 24,000 tons.

CONCLUSIONS.

The area in which coal beds of commercial grade occur is not as large as was formerly supposed and probably does not exceed 3 or 4 square miles. The shattered condition of much of the coal, due to rock movements, is unfavorable for handling and transportation. For this reason only a relatively small proportion of the output is likely to command a favorable price, and much of it must continue to be sold locally as run of mine or fine coal at low prices. The steep dip of the coal bed makes mining difficult and expensive and induces caving, such as has already blocked workings that might otherwise

²⁸ See analysis 29182 (p. 152) and section 5 (compare with section 4), fig. 14.

be productive. The variable and faulted character of the coal limits the extent to which a given mine can be worked. The disposal of water in the mines will increase the cost of production in those workings that lie beneath the level of the tunnel. If the projected improvements are completed and sufficiently favorable prices can be obtained for the product to offset the installation, operation, and amortization charges, there is probably enough coal in the ground to keep the mine running for a number of years. The future activity of the mines will depend in large measure on how well the operators are able to compete with Utah or Wyoming coals of equal or better grade (see table, p. 152) shipped in by rail.

An account of the Horseshoe district by G. W. Evans,¹⁹ published since the completion of the present paper, gives a description in which the geologic features are based on Woodruff's report. Although an estimate of 11,000,000 tons is given by Evans, he is careful to add the following qualifying statement, which should not be overlooked: "No one is justified in assuming that this amount of coal has been proved in this district. * * * The actual tonnage can be determined only by actual gangway and slope development." The following analyses are given:

Analyses of coals from Horseshoe district.

Bell Gulch bed.

[See p. 94 of report cited for section.]

	Air dried.	As received.	Moisture free.	Moisture and ash free.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Moisture.....	2.7	8.4	.....	.....
Volatile matter.....	41.3	38.9	42.5	45.2
Fixed carbon.....	50.4	47.4	51.7	54.8
Ash.....	5.6	5.3	5.8	.....
Air-dry loss 6.2 per cent.				

Brown Bear bed.

[See p. 94 of report cited for section.]

	2.7	7.0	.....	.....
Moisture.....	2.7	7.0	.....	.....
Volatile matter.....	42.5	40.6	43.7	45.0
Fixed carbon.....	50.8	48.6	52.2	54.5
Ash.....	4.0	3.8	4.1	.....
Air-dry loss 4.6 per cent.				

Boise bed.

	3.6	9.1	.....	.....
Moisture.....	3.6	9.1	.....	.....
Volatile matter.....	42.1	39.7	43.7	45.1
Fixed carbon.....	51.4	48.5	53.3	54.9
Ash.....	2.9	2.7	3.0	.....
Air-dry loss 6.1 per cent.				

¹⁹ Varley, Thomas, and others, A preliminary report on the mining districts of Idaho: Bur. Mines Bull. 166, pp. 90-103, 1919.

MAHOGANY CREEK.

Several coal prospects in the Cretaceous rocks on the north side of Mahogany Canyon, in the NW. $\frac{1}{4}$ sec. 15, T. 4 N., R. 44 E., were opened in carbonaceous shale of probably either Bear River or Wayan age. They give little promise of workable coal. A reported "coal" prospect in the south fork, which was not visited, is with little doubt in the phosphatic shale belt of the Phosphoria formation, which crosses the creek in the NE. $\frac{1}{4}$ sec. 21.

PATTERSON CREEK.

One of the two reported "coal" prospects in the basin of Patterson Creek was visited. This is approximately on the township line, in the SW. $\frac{1}{4}$ sec. 35, and proved to contain phosphate rock but not any coal. The other prospect is about a mile farther northwest, in the same belt of phosphatic shale.

SOUTH END OF TETON BASIN.

The road to Jackson ascends the valley of Trail Creek. Beyond the rhyolite the first ledges encountered are light-gray limestones that may be Cretaceous (Wayan). The road follows the strike of the beds rather closely but gradually cuts across Jurassic and lower beds. To the west lie Carboniferous rocks. Thus a fault of considerable magnitude passes up the valley of Trail Creek, cutting out the Cretaceous coal-bearing rocks.

NORTH END OF TETON BASIN.

The north end of Teton Basin is closed by rhyolite that forms prominent ledges in the vicinity of Tetonia. Associated with the rhyolite are beds of volcanic ash, including fragments of grayish-white pumice and black volcanic glass (obsidian). The glass has been mistaken by some persons for anthracite or coal.

On the Breckenridge ranch at Haden, in the NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 35, T. 6 N., R. 44 E., a well was sunk 15 years or more ago for oil. It has been commonly reported that 10 feet of coal was struck in this well at a depth of 600 feet. Upon visiting the locality the well was found in good condition with parts of the old broken derrick still standing. The writer is indebted to Mr. Preston K. Breckenridge, son of the former owner, for the following details regarding it.

The well was drilled under the direction of a man named McDonald from Florence, Colo. It had been intended to sink 3,000 feet but drilling stopped at about 700 to 760 feet. On the last day of drilling, when the men went to dinner, Mr. McDonald and one other man remained a few minutes at the well. The others after their

return from dinner resumed drilling and at once struck coal. After 10 feet of coal had been penetrated drilling stopped. Mr. McDonald then went to Denver to obtain further funds and additional machinery, but while there sickened and died. Some three or four years later Mr. Spencer Clawson, of Salt Lake City, had the well cleaned out and expended about \$1,000 in sampling and casing it. Special devices were employed in exploring the well for coal, but none was found. Both the elder Mr. Breckenridge and Mr. Clawson have since died. Mr. Preston Breckenridge states that his father had always felt that the well had been "fixed" before the reported coal was found. The well is cased to bedrock, 240 feet, and is 10 inches in diameter at the top and tapers to 8 inches at the bottom. No record of the character of the rock penetrated is available. Water stands in the well at a depth of 40 or 50 feet, as estimated by dropping a pebble. The well has been kept locked until recently but is now open.

BROADER STRUCTURAL FEATURES.

St. John,²⁰ Blackwelder,²¹ and Schultz²² have observed and figured the gently westward-dipping Paleozoic strata that pass beneath the lava along the west flank of the Teton Range on the east side of the basin. Schultz has made out anticlinal structure along the west side. Thus the structure of the basin appears with little doubt to be synclinal, as figured by Schultz. It was the opinion of Schultz that the syncline was deep enough to include coal-bearing Cretaceous beds and that commercial coal might be found by drilling at favorable points in the basin. The reported occurrence of coal in the Breckenridge well at Haden seemed to support this view.

PROBABILITY OF COAL.

One of the principal objects of the present examination was to procure data to test, if possible, the validity of the hypothesis just mentioned. As the basin is completely covered with Quaternary deposits to a depth of 240 feet at one locality, at least, and possibly to greater depths elsewhere, and is fringed with lava, inferences regarding the probability of the occurrence of coal beneath the cover must necessarily be drawn from the exposures and structure of the rocks surrounding the basin.

The Paleozoic exposures to the east have a structure so simple that they suggest equally simple structure for the concealed portions of

²⁰ St. John, Orestes, U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 411-424, pl. 34, 1879.

²¹ Blackwelder, Elliot, A reconnaissance of the phosphate deposits in western Wyoming: U. S. Geol. Survey Bull. 470, pp. 463-464, 1911.

²² Schultz, A. R., A geologic reconnaissance for phosphate and coal in southeastern Idaho and western Wyoming: U. S. Geol. Survey Bull. 690, p. 69, 1918.

the basin. The west side of the basin, however, exhibits many complications of structure, including pitching folds and branching thrust faults of considerable magnitude. It seems probable, too, that along the west side of the Horseshoe district close folds occur in the Cretaceous beds. Doubtless the more intensive effects of the thrusting may die out eastward, but it seems that a simple synclinal structure for the basin can not safely be assumed.

Again, the Cretaceous formations below the commercially important beds have a thickness of possibly more than 9,000 feet, so that there is no assurance that the syncline is deep enough to have carried the coal beds beneath the level of erosion, where they could have been preserved. If, as seems likely, the basin is a large complex syncline containing smaller folds, one or more synclines might be present and deep enough to hold coal measures, but the positions of these synclines could be determined only by systematic drilling, and the possibility of faults would add much uncertainty to the problem. The record of the Breckenridge well is inconclusive, because it now affords no information regarding the character of the bedrock.

If one were disposed to spend the necessary money to test the synclinal hypothesis the place to drill would be on the eastern slopes of the foothills east of the Horseshoe district or somewhat farther north and in the region between those slopes and Teton River. A few wells sunk on a northeast-southwest line to depths of 200 to 500 feet would probably suffice to indicate the geologic formation upon which the lava rests. If this should prove to be the Frontier formation, coal beds that could be profitably mined might be expected. Because of the gentler dips in the broad syncline the coal if present would probably be relatively free from the objectionable crumbling that characterizes the coal in the Horseshoe district and would thus be better adapted for transportation and marketing.

CONTINENTAL DIVIDE.

Two districts were visited on the Continental Divide, one at the headwaters of Cottonwood Creek in T. 14 N., Rs. 38 and 39 E. (unsurveyed), and the other at the head of Sheridan Creek, chiefly in T. 14 N., R. 40 E. (unsurveyed). Coal was found in the Cottonwood district but not in the Sheridan district.

COTTONWOOD CREEK.

GENERAL FEATURES.

The rocks of the Cottonwood district are chiefly Cretaceous sandstone, shale, and clay. The stratigraphic position is not definitely known, but they are presumed to be of Frontier or later age. They

have been exposed by the partial erosion of the overlying Tertiary conglomerate and lava. One coal bed of probable commercial importance is exposed, and there are several others each a few inches in thickness. Numerous landslides with fresh scars afford exposures of the rocks here and there, but debris accumulations of similar origin and patches of Tertiary conglomerate conceal much of the bedrock of the region. The Cretaceous rocks and some of the larger areas of Tertiary formations are shown in figure 13.

The strata have a general northwesterly to westerly strike and a dip of 13° – 39° SW. At the Scott & Bucy entry the strike is N. 69° W. and the dip is 16° SW. Toward the northeastern and southwestern parts of the district the dip steepens. These structural features are shown in structure section *D-D'*, figure 12, for which, as well as for figure 13, sheet 4 of the United States Forest Service map of the Targhee National Forest was used as a base.

The outcrop of the coal can be traced for only about a quarter of a mile, and a traverse through the country to the east failed to strike the continuation of the bed in that direction. The accumulation of debris above noted and the vegetation might readily conceal it. There is no apparent reason, however, why the coal should not continue eastward. In fact, it is desirable that the approximate area presumed to be underlain by it outside the Tertiary cover should be shown on the map. Accordingly, on the basis of the available readings of strike and dip and the topography, the inferred position of the line where the bed should crop out is indicated on the map by a dotted line. The region southwest of this line may be tentatively regarded as underlain by the coal bed at depths varying in the manner suggested by the structure section. The exact position of the bed at any particular locality will have to be determined by drilling.

A dike of dark amygdaloidal lava occurs in the SE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 18, T. 14 N., R. 39 E. (unsurveyed; location estimated from topography). It is accompanied on the west by a breccia 5 or 6 feet thick composed of sandstone and clay cut by stringers of lava and containing pieces of lava. The sandstone to the south strikes N. 55° W. and dips 23° S. A small pocket of black, coaly shale occurs in the breccia. Thin pieces of sandstone float containing carbonaceous flakes were found on the south side of the dike. Beneath the sandstone is a light gray clay. The dotted line representing the theoretical position of the projected coal bed crosses the line of the dike. The coal was not found here, but the pocket of coaly shale suggests its proximity.

Northwestward the coal bed probably continues an unknown distance into Montana. Two traverses were made north of the divide, but the bed was not found. The region is thickly timbered and obstructed by landslide debris and bogs, and one might readily pass within a few feet of an exposure or prospect without being aware of

its presence. A large slide was found about three-quarters of a mile northwest of the Scott & Bucy entry, in which occur fragments of coal and a massive bed of fossiliferous light-gray sandstone. The fossils here are different from those at the entry, and the horizon is therefore probably not the same but perhaps stratigraphically lower. The coal bed, though not exposed, is probably much thinner than at the entry. The northward continuation of the Cretaceous formation and other geologic data in Montana, as shown on the general map (Pl. XIV), are taken from a map by Condit and Finch.²²

DEVELOPMENT.

The Scott & Bucy entry is driven in rock down the dip of the coal bed and is untimbered. It trends N. 47° E. and is 110 feet long. The roof of the entry is of slabby sandstone, in places somewhat broken and dangerous. Some falls of rock have already obstructed the passage. At the time of the writer's visit no work had apparently been done within two or three years. The location notice is dated July 24, 1912, and the locators are C. W. Scott, of Dillon, and M. W. Bucy, of Monida, Mont.

CHARACTER OF COAL.

The coal bed is exposed along the walls of the entry its entire length and shows little change in character or thickness. About 50 feet from the portal a small normal strike fault lowers the bed 2 feet on the west. The coal at the face of the entry is relatively fresh and fairly hard. It did not appear to break more easily in one direction than in another. The following section was measured at the face of the entry, where the strike of the coal is N. 60° W. and the dip 16° W.:

Section of coal bed at Scott & Bucy mine in the SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 11, T. 14 N., R. 38 E. (unsurveyed) Boise meridian, Idaho.

	Ft. in.
Clay, gray; grades upward into sandstone-----	6
Coal, sheared and slickensided; pinches out eastward-----	6
Clay, gray-----	6
Coal,* hard, dense-----	2 8
Clay, black, partly bone-----	7
Clay, gray-----	3
	5 0

The following analysis of coal, presumably from the same opening, is contributed by Mr. Scott in correspondence with the Survey:

* Condit, D. D., and Finch, E. H., personal communication.

** See analysis 29281 (p. 152) and section 7, fig. 14.

Analysis of coal from Scott & Bucy claim.

[Analyst not stated.]

Moisture	3.70
Volatile matter	27.09
Fixed carbon	59.29
Sulphur	.01
Ash	9.91
Heating value (British thermal units)	13,050

This analysis appears to indicate coal of a considerably higher grade than that from which sample 29281 (p. 152) came, and was doubtless made from a picked sample of coal. Sample 29281 was taken from a channel across the entire face of the bed in the general manner prescribed by the Bureau of Mines.²⁵ Differences in methods of sampling or of analysis might account in part for the discrepancy between the two analyses. The difference may also be due to the proximity of the Scott & Bucy sample to a dike. The face of the entry where channeled for sampling, although seemingly fresh, had been exposed to the air for two years or more, and the coal bed had doubtless suffered changes by weathering. No tests of the coking qualities of the coal are available.

According to analysis 29281 the coal would be considered as of subbituminous rank or low rank bituminous. Its heating value (10,062 British thermal units for the air-dried sample) is less than that of the coals of the Horseshoe district or of the Wyoming coals cited for comparison in the table on page 152. To judge from the condition of the exposure along the walls of the entry it would not slack readily on exposure to weathering and would probably stand hauling and transportation.

ACCESSIBILITY.

Although in an air line the mine lies within 15 miles of Beaver or Humphrey, on the Butte branch of the Oregon Short Line Railroad, the actual haul to the railroad would be much longer. By way of Kilgore the distance from the coal bed to Spencer, the nearest railroad point south of the divide, is approximately 27 miles. On the north side of the divide the distance to Monida, by way of Jones Creek and Centennial Valley, is approximately the same. Further exploitation of the field north of the divide might disclose more favorable points of access nearer Centennial Valley, but even then the distance from the present railroad would exceed 15 miles.

A well-traveled and well-graded wagon road leads up East Camas Creek to a point within about $2\frac{1}{2}$ miles of the coal entry. On the north side of the divide a road, now somewhat out of repair, has

²⁵ Holmes, J. A., The sampling of coal in the mine: Bur. Mines Tech. Paper 1, 1911.

been constructed up Jones Creek to the divide. The grade for the last mile is very steep.

OUTLOOK.

The country both north and south of the divide is so sparsely settled that there is doubt if it could soon afford a sufficient market to warrant the development of mines in this field. The thickness of the bed, the quality of the coal, and the size of the field would not in themselves justify the construction of spur tracks to the mine, but should other causes cooperate in bringing a railroad sufficiently near profitable mines might be developed

ANALYSES.

The accompanying analyses were made at the Pittsburgh laboratory of the Bureau of Mines. Four forms of analysis are given for each sample. A represents the material as received at the laboratory, essentially as it is found in the mine. B represents the coal after drying to a constant weight at a temperature of 30° to 35° C. This form of analysis is best adapted to general comparisons. C represents the coal after all moisture has been removed. D represents the coal after both moisture and ash have been eliminated. C and D are theoretical forms derived from A and B by recalculation.

The samples analyzed have all been collected in accordance with the regulations of the Bureau of Mines, which require, in brief, that the face to be sampled must be cleared of weathered coal, powder stains, and other impurities and channeled across the bed to obtain the sample. Materials from large partings and lumps of impurities are rejected. The sample is collected on a sampling cloth, broken up to pass through a $\frac{1}{2}$ -inch mesh sieve, thoroughly mixed and quartered, and the alternate quarters rejected. Mixing and quartering are repeated until the sample is reduced to about 4 pounds. This residue is then placed in a can, which is sealed and forwarded to the laboratory.

Analyses of two Wyoming coals are included in the table for comparison.

Analyses of coal samples from eastern Idaho and adjacent regions.

[Made at the Pittsburgh laboratory of the Bureau of Mines: A. C. Fieldner, chemist in charge.]

Locality.	Laboratory No.	Air-drying loss.	Form of analysis.	Proximate.				Ultimate.					Heating value.	
				Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydro-gen.	Carbon.	Nitrogen.	Oxygen.	Calories.	British thermal units.
Brown Bear mine, Horseshoe district, SE. $\frac{1}{4}$ sec. 26, T. 5 N., R. 43 E.	15115	8.3	A	11.5	37.2	47.0	4.30	0.54	5.94	68.09	1.40	19.73	6,720	12,090
			B	3.4	40.6	51.3	4.69	.59	5.47	74.25	1.53	13.47	7,325	13,190
			C	.....	42.0	53.1	4.86	.61	5.27	76.89	1.58	10.79	7,560	13,660
			D	.....	44.2	55.8	.....	.64	5.54	80.82	1.66	11.34	7,975	14,360
Beallut mine (probably Woodruff's locality) SW. $\frac{1}{4}$ sec. 31, T. 5 N., R. 44 E.	20182	4.8	A	7.7	39.6	48.2	4.53	.54	5.94	70.82	1.37	16.80	6,985	12,580
			B	3.1	41.6	50.6	4.76	.58	5.68	74.35	1.44	13.20	7,335	13,200
			C	.....	42.9	52.2	4.91	.58	5.51	76.71	1.48	10.81	7,565	13,630
			D	.....	45.1	54.9	.....	.61	5.70	80.67	1.56	11.37	7,965	14,320
Horseshoe mine, NW. $\frac{1}{4}$ sec. 6, T. 4 N., R. 44 E.	15116	4.3	A	7.7	39.7	50.4	2.2	.38	.....	.....	.....	.....	7,155	12,880
			B	3.6	41.5	52.6	2.3	.40	.....	.....	.....	.....	7,475	13,460
			C	.....	43.0	54.6	2.4	.41	.....	.....	.....	.....	7,755	13,960
			D	.....	44.1	55.9	.....	.42	.....	.....	.....	.....	7,945	14,300
Prospect at Pine Creek Pass, sec. 24, T. 3 N., R. 44 E. (unsurveyed).	20280	14.3	A	20.3	20.1	29.0	30.6	1.12	.....	.....	.....	.....	3,515	6,320
			B	7.1	23.4	33.8	35.7	1.31	.....	.....	.....	.....	4,100	7,380
			C	.....	25.2	36.4	38.4	1.41	.....	.....	.....	.....	4,410	7,940
			D	.....	41.0	59.0	.....	2.29	.....	.....	.....	.....	7,160	12,860
Scott & Buoy entry, SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 11, T. 14 N., R. 38 E. (unsurveyed).	20281	7.9	A	18.4	31.1	40.1	10.4	.71	.....	.....	.....	.....	5,150	9,270
			B	11.4	33.7	43.5	11.4	.77	.....	.....	.....	.....	5,560	10,060
			C	.....	38.1	49.1	12.8	.87	.....	.....	.....	.....	6,310	11,350
			D	.....	43.7	56.3	.....	1.00	.....	.....	.....	.....	7,235	13,020
Union Pacific mine No. 1, Rock Springs, Wyo.	5356	2.3	A	8.5	35.6	50.4	5.48	.78	5.26	66.15	1.19	21.04	6,575	11,830
			B	6.4	36.4	51.6	5.61	.80	5.22	67.71	1.22	19.44	6,780	12,110
			C	.....	38.9	55.1	5.99	.85	4.82	72.32	1.30	14.72	7,185	12,940
			D	.....	41.4	58.6	.....	.90	5.13	76.93	1.38	15.66	7,645	13,760
Diamondville No. 1 mine, Kemmerer, Wyo.	2284	1.3	A	5.1	40.5	49.8	4.61	.49	6.63	72.95	1.18	15.14	7,200	12,960
			B	3.9	41.0	50.4	4.67	.50	5.56	73.91	1.20	14.16	7,295	13,000
			C	.....	42.7	52.4	4.86	.52	5.33	76.89	1.24	11.16	7,590	13,660
			D	.....	44.9	55.1	.....	.54	5.61	80.82	1.31	11.72	7,990	14,360

OCCURRENCE OF OIL.

Reported indications of oil were investigated on Mahogany Creek, on the west side of Teton Basin, and in Darby Canyon, on the east side. On Mahogany Creek swamp slime with iridescent iron films was mistaken for oil, and in Darby Canyon the gently undulating and faintly westward-dipping Carboniferous limestone near the old saw-mill was thought to have a favorable structure for the accumulation of oil. It was also reported that oil scum was common on the creek at certain seasons of the year. The stream at the time of the examination was exceptionally free from scum of any kind, although a collapsed bridge near the sawmill afforded excellent opportunities for the gathering of oil. The Carboniferous rocks alluded to are part of the thick Paleozoic strata that form the west flank of the Teton Range. With the exception of the phosphatic shale of the Phosphoria formation, which yields small amounts of petroleum on destructive distillation,²⁶ the Paleozoic rocks are not known to bear significant amounts of oil in this portion of the Rocky Mountains. Many of them, however, when struck with a hammer or freshly broken, give a fetid odor like that of crude petroleum. The dip and exposure of the strata are such as to afford ready opportunity for the escape of such hydrocarbons as may have been present in these rocks.

The coal bed and some of the shale beds at the Brown Bear mine yield small quantities of petroleum upon destructive distillation.²⁷

The anticline along the west side of the basin east of the Horseshoe district, as noted by Schultz,²⁸ furnishes the most promising structure in the region for the accumulation of oil. The axial portion and eastern limb of this fold are largely concealed by lava, and to the west faults occur in parts of the district. The gathering area for oil apparently is not large. The presence of oil could be determined only by drilling, which should not be undertaken without full realization of the cost and the great chance of failure.

²⁶ Condit, D. D., Oil shale in western Montana, southeastern Idaho, and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 711, p. 81, 1919. Schultz, A. E., *op. cit.*, pp. 80, 81.

²⁷ Condit, D. D., *op. cit.*, pp. 82, 83.

²⁸ Schultz, A. E., *op. cit.*, p. 79.



DEPARTMENT OF THE INTERIOR

JOHN BARTON PAYNE, Secretary

UNITED STATES GEOLOGICAL SURVEY

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**COAL IN THE MIDDLE AND EASTERN PARTS OF
SAN JUAN COUNTY, NEW MEXICO**

BY

CLYDE MAX. BAUER

AND

JOHN B. REESIDE, JR.

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COAL IN THE MIDDLE AND EASTERN PARTS OF SAN JUAN COUNTY, NEW MEXICO.

By CLYDE MAX. BAUER and JOHN B. REESIDE, Jr.

INTRODUCTION.

From the earliest settlement of southwestern Colorado down to the present time the great coal bed, nearly 50 feet thick, exposed in the canyon of Animas River, 2 miles below Durango, Colo., has attracted general attention. It is true that this bed is not all coal, and attempts to mine it in competition with the better coals lower in the geologic sequence have proved failures. Nevertheless, many persons have speculated regarding its southward extension, and this has led to prospecting in the strip of land lying between the Colorado boundary and San Juan River. The character and size of this and associated beds north of the river have thus been ascertained, but until recently little exact information has been available concerning these beds in the inhospitable region south of San Juan River. In the summers of 1915, 1916, and 1917 the writers procured detailed information regarding the coal beds north of the San Juan, crossed the river, and traced the coal-bearing formation as far as Alamo Arroyo, on the south line of T. 22 N., R. 9 W., where the formation ceases to bear coal beds of commercial value, and thus were able to delimit the field on the west side of the San Juan Basin.

From the Colorado-New Mexico boundary line this field extends through the central and southern parts of San Juan County, which occupies the extreme northwest corner of New Mexico. The outcrop of the coal-bearing Fruitland formation trends southwestward from the State boundary, near the point where it is crossed by La Plata River, to San Juan River. Beyond the San Juan the outcrop parallels Chaco River very closely the entire distance to Alamo Arroyo, near the south side of San Juan County. (See Pl. XVI.) The coal is chiefly of subbituminous rank and is similar to that of the Gallup district, but in the northern part of the field it is good enough to be ranked as bituminous. The beds, numbering from two to six at most localities, range in thickness from a few inches to 40 feet. In the following pages the thickness of various beds at many places is given, and the quality and character of the coal and the inclosing strata are described.

ACCESSIBILITY OF THE FIELD.

The field may be reached from the north by the Denver & Rio Grande Railroad, a standard-gage branch of which extends from Durango, Colo., to Farmington, N. Mex., on San Juan River in north-central San Juan County. Access to Durango may be had by several routes. Travelers from the west may go from Grand Junction, Colo., on the main line of the Denver & Rio Grande Railroad, by way of Montrose, Vance Junction, and Mancos. The total distance from Grand Junction to Farmington is 300 miles, and the trip requires transshipment of passengers and freight from standard-gage cars to narrow and then from narrow to standard. From the east the traveler may go from Denver and Pueblo, by way of Walsenburg or Salida to Alamosa; thence over the Cumbres Pass (elevation, 10,000 feet) to Durango. The total distance from Denver to Farmington is 496 miles, and two transshipments are required because of changes in track gage. Another route goes from Denver by way of Salida, Marshall Pass (elevation, 10,850 feet), Montrose, Vance Junction, and Mancos. The total distance from Denver by this route is 585 miles, and two transshipments are required. On all these routes grades are heavy, maintenance and operation costs are large, and transportation is therefore relatively slow and expensive.

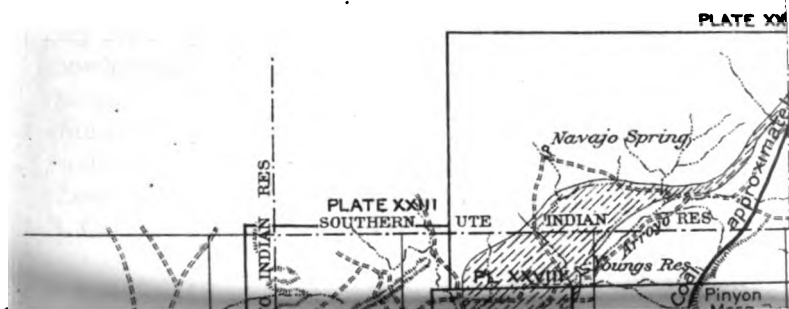
From the south the field may be reached by wagon from stations on the Atchison, Topeka & Santa Fe Railway. Roads run from Guam, Thoreau, and Baca through several passes in the high ridges that lie a few miles north of the railroad. The trail from Thoreau through Satans Pass as far as the Pueblo Bonito Agency and Indian school at Crownpoint is well kept, but elsewhere the roads are unimproved. The distance from the railroad to the southern edge of the field is 60 miles; to Farmington it is 100 miles. This route requires a hard trip through nearly uninhabited country in which water is available at only a few points, and there are many arroyos to cross—a difficult task when heavy rainstorms or melting snow have supplied enough water to flow or erosion has cut the banks to steep angles.

From Gallup an automobile stage runs northward along a line about 10 miles west of the field, crossing the San Juan at Shiprock, in T. 30 N., R. 18 W., and thence following up the river to Farmington. More direct wagon routes from Gallup to the field are also available but have all the disadvantages of those from other points.

FIELD WORK AND ACKNOWLEDGMENTS.

The field work on which this report is based was done during the summers of 1915, 1916, and 1917. In the absence of a suitable base map, several base lines were measured, from which control points were located by triangulation with plane table and telescopic alidade. From these points detailed mapping was extended through the field.

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difficult to cross with a team.

these points detailed mapping was extended through the field.

The field party of 1915, in charge of the senior author, was composed of H. R. Bennett, J. C. Brittain, Royce Brown, and the authors. The party of 1916 included Frank R. Clark, J. E. Heald, J. H. Eiseman, and the junior author, and that of 1917 included Harvey Bassler, K. N. Garard, J. F. Gibbs, and the junior author. Acknowledgment of the efficient aid rendered in the prosecution of the project is due to all these men, particularly Mr. Bassler, who procured all the field data for the region north of T. 30 N., R. 15 W. The authors also wish to thank many residents of San Juan County for hospitality and for courtesies rendered the field parties, and M. R. Campbell for advice and assistance in the field and office work.

SURFACE FEATURES.

LAND FORMS.

This field has a maximum relief of nearly 2,500 feet. The lowest point is on the San Juan near the western edge of the field and is about 5,000 feet above sea level; the highest point is on the southeastern edge of the field and is about 7,500 feet above sea level.

Along the western edge abrupt tilting of resistant rocks and subsequent erosion of the softer materials has formed a striking ridge known as the Great Hogback, Hogback Mountain, or simply the Hogback—a sharp ridge of sandstone whose eastern face is a steep dip slope rising as much as 700 feet above the adjacent country. To the north the Hogback passes into a series of lower parallel ridges and ceases to be a prominent feature.

North of San Juan River the country for some distance east of the Hogback is a fairly even surfaced shale valley, which is known locally as the Meadows. It contains some low sandstone ridges and some badlands. It is unoccupied, though it could probably be successfully cultivated if water were available. Wells drilled for oil in this part of the field have found only salt water.

The remainder of the field is essentially a dissected plateau. (See Pls. XVII and XVIII.) The drainage lines are all entrenched below the upland plain and are separated by flat-topped divides which are clearly parts of a former continuous surface. Here and there isolated remnants stand out prominently—for example, Pinyon Mesa, in T. 30 N., R. 14 W. Along the arroyos there are extensive badlands, which are all cut below the general surface and are invisible from it at relatively short distances. (See Pl. XVIII.)

Sand dunes are abundant on the interstream areas. Sand from the arroyos and dry creek beds is blown in enormous volume out upon the flats and forms large dunes and sand ridges. The surface forms in some parts of the field are much modified in this way. Along the east bank of Chaco River, owing to the prevailing westerly winds, dunes and sand flats are abundant and form a barrier in many places difficult to cross with a team.

Along the large streams, especially the San Juan, there are three or four river terraces, the highest of which is particularly well shown about Farmington and Fruitland. Others are recognizable also at these localities, Farmington itself being built on a terrace 50 feet above the present level of the river.

DRAINAGE AND WATER SUPPLY.¹

The streams of this field belong to the Pacific drainage system. San Juan River receives all the other streams, and its waters, through Colorado River, reach the Gulf of California. The Continental Divide lies 15 miles southeast of the field represented on the map.

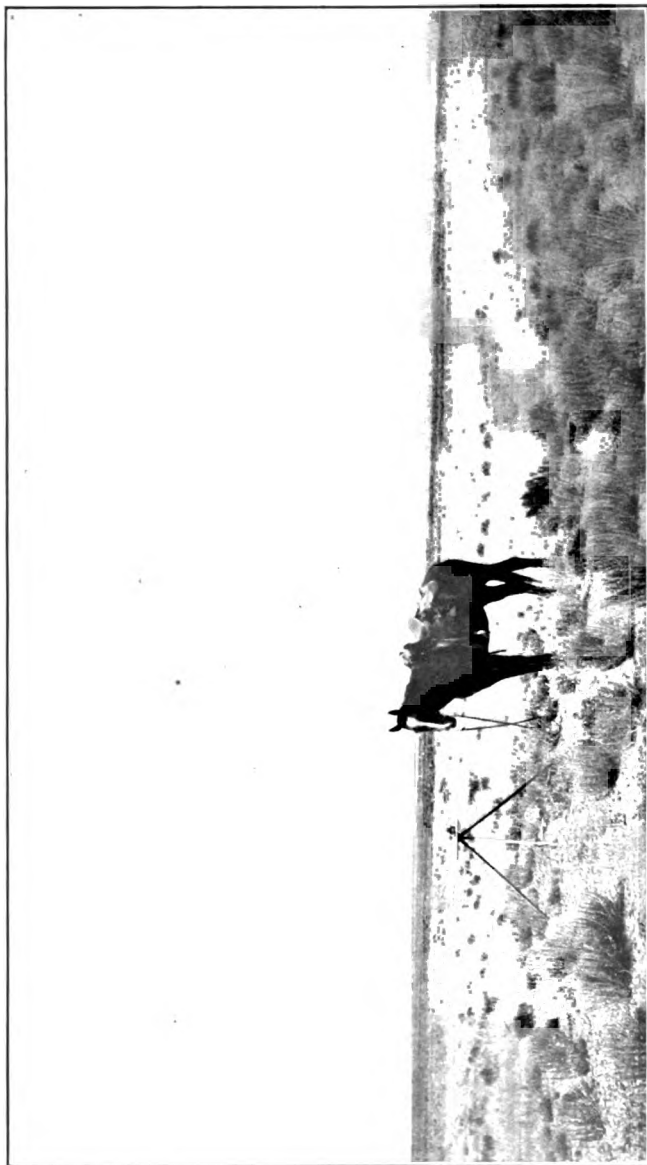
Three perennial streams flow through the region—La Plata, Animas, and San Juan rivers. These streams head in the high mountains of southwestern Colorado and depend for their volume largely on melting snow. The amount of water they carry consequently varies greatly with the season of the year, though it is always enough to permit irrigation of the valleys.

Except in the valleys of these three perennial streams, water is scarce. Even the largest tributaries to these streams contain running water only after the heaviest rains, and Chaco River itself is ordinarily but a wide strip of dry sand. However, water is generally near the surface of the sand in the channels of the arroyos and can be obtained by digging 4 or 5 feet. It varies much in quality but is in general strongly impregnated with mineral salts. Springs, seeps, and other natural watering places are exceedingly rare. The Indians of the region have built a number of reservoirs and sunk shallow wells near the arroyos, which are easy to reach when their location is known and which form the main reliance of the traveler for his water supply. At a few points in Gallego Arroyo wells have been drilled that supply water by pumping. Most of this water carries enough alkali or salt to make it unpalatable.

CLIMATE AND VEGETATION.

This field is part of an arid region whose climate is marked by great variability. Very hot days may be followed by very cool nights; no rain may fall for a month, and then a single shower may bring a normal month's rainfall; the normally rainy months may be absolutely dry and the normally dry months relatively wet. The normal annual precipitation is about 7 inches for the San Juan Valley, though in exceptional years it may rise to nearly 20 inches or fall as low as 3 or 4 inches. For the entire field it is usually under 10 inches. The temperature fluctuates widely—below 0° for the minimum and well above 100° for the maximum. The mean

¹ See also Gregory, H. E., *The Navajo country; a geographic and hydrographic reconnaissance of parts of Arizona, New Mexico, and Utah*: U. S. Geol. Survey Water-Supply Paper 380, 1916. French, J. A. (State engineer), *Surface water supply of New Mexico, 1888-1917*, Albuquerque, N. Mex., 1918.



THE PLATEAU SURFACE VIEWED NORTHWESTWARD ACROSS THE VALLEY OF CHACO RIVER, N. MEX., SOUTH OF HUNTER WASH.

annual temperature at Fruitland is 52.6°, and the annual range is about 115°. A daily range of 40° is not uncommon. The summer storms are usually short but violent, with high winds, lightning, and sometimes heavy rain and hail. The winter storms are often accompanied by snow.

The native vegetation is entirely of types adapted to arid conditions of life. The lowest lands bear greasewood (*Sarcobatus*), sagebrush (*Artemisia*), and bunch grasses. Higher lands (up to 6,000 feet) bear rubberweed (*Hymenoxys*), cactus (mainly *Opuntia*), sagebrush, grasses, and scattered juniper (*Juniperus monosperma*) and piñon (*Pinus edulis*). Where very sandy they support a growth of joint fir (*Ephedra*) and redtop grass. Above an elevation of 6,000 feet the chief elements of the flora are juniper and piñon and the minor elements are sagebrush and other shrubby plants, with some jack pine and scrub oak.

By means of irrigation it is possible to raise a number of plants not native to the region. Fruit of various kinds thrives and in most years brings abundant returns. Alfalfa grows well, and some grain, potatoes, tomatoes, and other vegetables are produced. Markets for farm produce are strictly limited by the transportation conditions, and in the best years much more can be raised than there is any possibility of selling.

The Navajo Indians, by means of a system of storm-flood irrigation, succeed in raising fair crops of certain varieties of maize, melons, beans, and a few potatoes in bottom lands, where the soil is rich and gets the benefit of any heavy rains which may fall.

SETTLEMENTS AND ROADS.

Aztec and Farmington are the two main towns of the field. Aztec is the county seat and has a population of 500. Farmington is the terminus of a branch of the Denver & Rio Grande Railroad and has a population of 800. Both are essentially trading centers and supply points for the country about them and are well supplied with stores, banks, and other necessary institutions.

Beside these larger towns there are several scattered settlements on San Juan River, including Blanco, Bloomfield, Kirtland, Fruitland, and Liberty; several on La Plata River, including La Plata and Pendleton; and several on Animas River, including Flora Vista, Inca, and Cedarhill. Most of these are post offices, with one or two stores. South of San Juan River there are a number of isolated trading posts outside of the Navajo Reservation which depend on the Indians for their existence. The location of many of these posts is shown on the map (Pl. XVI). There are very few white settlers outside of the irrigated districts.

Along the perennial streams the roads are kept in good condition and are normally passable for automobiles as well as wagons, but

outside of these districts they are usually mere unimproved wagon trails. These trails are numerous, thanks to the Indian propensity for moving about, though badlands, sand dunes, and rapidly eroding arroyos present many difficulties to the traveler. It is possible to take heavy camp wagons over most of the roads shown on the accompanying maps, but automobiles meet with difficulties in crossing deep arroyos and steep-walled ditches.

Animas and La Plata rivers may be forded at many places, but the San Juan is treacherous and difficult to ford in the spring and summer. The two smaller streams are bridged at a number of places, and the San Juan at Blanco, 20 miles east of Farmington, at Farmington, and at Ship Rock, 35 miles by road west of Farmington. At Bloomfield a ferry operates during periods of high water, and at Fruitland there is a footbridge.

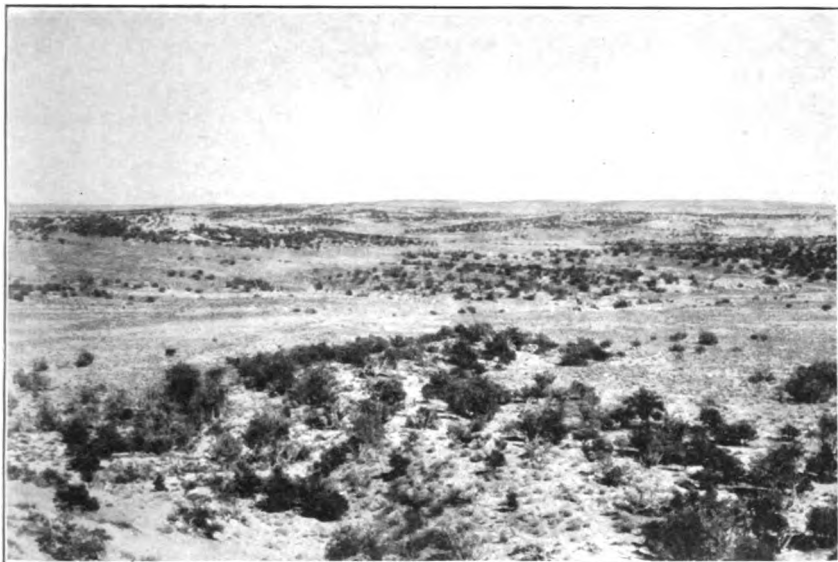
LAND SURVEYS.

The land surveys of parts of the region covered in this report were made in recent years, and the monuments are easily found. Tps. 24 to 28 N., R. 13 W.; part of T. 23 N., Tps. 25 to 28 N., R. 12 W.; Tps. 27 and 28 N., Rs. 11 and 10 W.; and Tps. 29 and 30 N., Rs. 16, 17, and 18 W., were surveyed in 1913. T. 30 N., Rs. 15 and 14 W., was surveyed in 1909. Tps. 21 and 22 N. and part of T. 23 N., R. 13 W., were surveyed in 1893, and although no corners for these townships were found in the field, the geographic details shown on the plats are accurate. The townships between San Juan River and the Colorado-New Mexico State boundary were surveyed mostly during the eighties, and though the corners are not easily found the details shown on the plats are fairly accurate. In the area included in Tps. 21 to 24 N., R. 12 W.; Tps. 21 to 26 N., Rs. 9 to 11 W.; and Tps. 21 to 24 N., Rs. 7 and 8 W., however, no authentic corners were found, and the details shown on the official plats disagree so profoundly with the districts they are supposed to represent that it seems doubtful if the surveys were ever made. The lines shown for this portion of the area mapped are based on relocations of a few corners by local surveyors and the Office of Indian Affairs and must be considered provisional. In the part of the field covered by the net based on the Navajo meridian the lines must also be considered provisional, as little evidence of their position was obtained in the field.

GEOLOGY.

GENERAL FEATURES.

The stratified rocks of this region consist of a succession of sandstone, shale, coal, and conglomerate, laid down originally as marine.



A. CHARACTERISTIC TOPOGRAPHY AND VEGETATION OF THE HIGHEST PART OF THE SAN JUAN COAL FIELD, N. MEX.



B. EXPOSURE OF PUERCO AND TORREJON FORMATIONS MAKING BADLANDS 1½ MILES ABOVE OJO ALAMO STORE, N. MEX.

brackish-water, and fresh-water sediments. The rocks here have been depressed or those in surrounding regions have been uplifted until they lie in the form of an immense basin that stretches from Durango, Colo., on the north, a distance of 125 miles to Gallup, N. Mex., on the south. From the Hogback eastward to Cuba or Gallina, N. Mex., the basin is more than 100 miles across. In the center of the basin the rocks are supposed to be practically flat, but in the rim they are sharply upturned. This is illustrated by a dip of 45° E. in the Great Hogback, which near Liberty post office forms the western rim, dips of only 1° to 3° in the outcrop of the Fruitland formation near by, and dips of 1° or less in the younger beds.

Minor structural features superimposed on this general basin are not numerous in the San Juan County field. Several broad, low anticlines cross the rim at right angles north of San Juan River, but they are noticeable chiefly in the bulges they make in the outcrop lines of the formations. A small, sharper anticline occurs in T. 30 N., R. 15 W., and another in T. 25 N., R. 16 W. (unsurveyed). In T. 30 N., R. 15 W., there is some evidence of a flattening of the dip to form a structural terrace parallel to the basin rim; in T. 29 N., R. 16 W., likewise an obscure structural terrace is observable in the Lewis shale. The only fault large enough to map was seen in T. 22 N., R. 7 W., but it is relatively small.

The Great Hogback is formed by the tilting of the resistant rocks of the Mesaverde group in the sharp monocline known as the San Juan fold. The dip flattens very quickly in the Lewis and Mancos shales, so quickly that at first glance the structure looks as if faulted. However, good exposures show only a rapid but continuous change in the dip. Toward the north the axis of the fold shifts eastward, and in T. 31 N., Rs. 13 and 14 W., and T. 32 N., R. 13 W., the steepest dips are in the Fruitland formation and the Kirtland shale, while the rocks of the Mesaverde group flatten to form the prominent southern extension of the tableland known as Mesa Verde. Farther to the north the fold is not very distinct.

The following table gives the names and thicknesses of the formations and summarizes the stratigraphy:²

² For a description of the fossils and a discussion of the correlations see Bauer, C. M., and others, Contributions to the geology and paleontology of San Juan County, N. Mex.: U. S. Geol. Survey Prof. Paper 98, pp. 271-353, 1916; Gilmore, C. W., Reptilian faunas of the Torrejon, Puerco, and underlying Cretaceous formations of San Juan County, N. Mex.: U. S. Geol. Survey Prof. Paper 119, 1919; Sinclair, W. J., and Granger, Walter, Paleocene deposits of the San Juan Basin, N. Mex.: Am. Mus. Nat. Hist. Bull., vol. 33, pp. 297-316, 1914; Granger, Walter, Notes on Paleocene and lower Eocene mammal horizons of northern New Mexico and southern Colorado: Am. Mus. Nat. Hist. Bull., vol. 37, pp. 821-830, 1917.

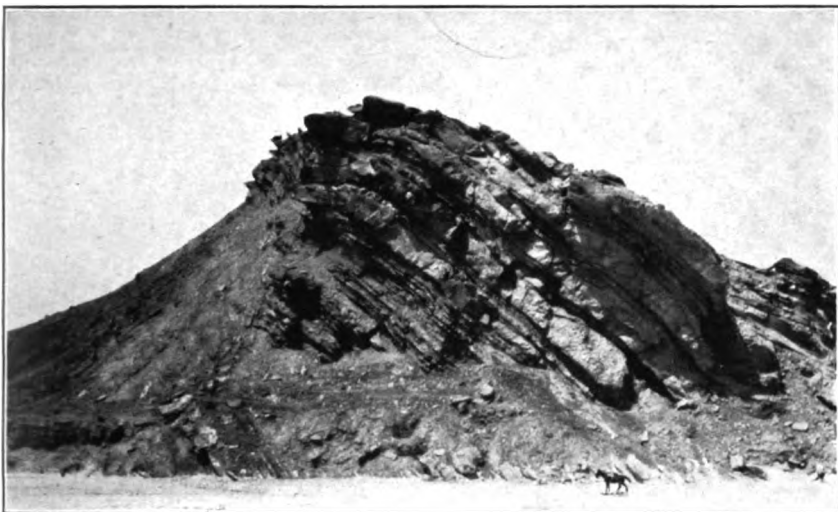
Geologic formations in middle and eastern San Juan County, N. Mex.

Age.	Formation.	Character.	Thickness (feet). ^a		
			1	2	3
Eocene.	Wasatch formation.	Massive buff to yellow conglomeratic sandstone, interbedded with variegated shale; red shale abundant. Fluvialite.	(?)	(?)	(?)
	Formation undetermined.	Light-gray shale with some darker-gray and some red layers and some soft white conglomeratic sandstone. May be part of Wasatch formation. Fluvialite.	(?)	(?)	250
	Torreon and Puerco formations.	Gray shale and lenticular soft white sandstone with bands of colored shale; yellow firmer sandstones, with concretions. Fluvialite.	1,400	(?)	390-1,140
Upper Cretaceous.	Ojo Alamo sandstone. ^c	White, gray, or brown conglomeratic sandstone containing varicolored shale lenses. Fluvialite.	(?)	400	63-129
	Kirtland shale (including Farmington sandstone member).	Blue-gray shale banded with yellow and brown. Farmington sandstone member, near middle of the Kirtland, made up of a number of channel sandstones. Fluvialite.	950	836	700-1,180
	Fruitland formation.	Gray sandy shale and gray-white cross-bedded sandstone and buff sandstone, with coal beds. Of fresh and brackish water origin.	425	241	230
	Pictured Cliffs sandstone.	Buff to light-yellow and gray sandstone interbedded with thin gray shale. Marine.	210-240	275	50-70
	Lewis shale.	Greenish-gray sandy shale with scattered lenses of buff sandy limestone. Marine.	^b 1,100-1,710	475	75-140
	Mesaverde group.	Cliff House sandstone.	^b 390	750	369
		Menefee formation.	^b 356	1,076	(?)
		Point Lookout sandstone.	^b 274	300	(?)
	Mancos shale.	Dark-gray and dark-drab shale. Marine.	(?)	(?)	(?)

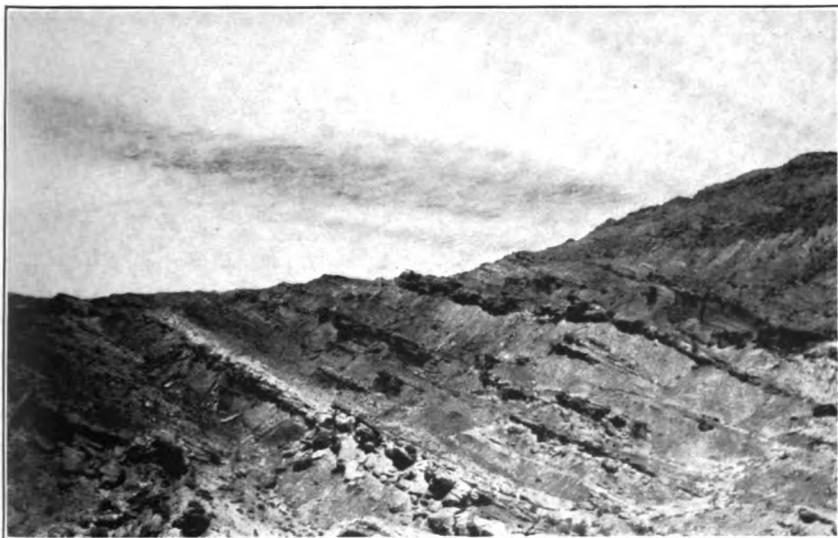
^a 1, Northern San Juan County, N. Mex., and southern La Plata County, Colo.; 2, central San Juan County (San Juan River), N. Mex.; 3, southern San Juan County, N. Mex.

^b Unpublished data collected by Max A. Pishel in Colorado.

^c See footnote 5a, p. 173.



A. PART OF THE MESAVERDE GROUP IN THE GAP CUT THROUGH THE GREAT HOGBACK BY CHACO RIVER, N. MEX.



B. THE MENEFEER FORMATION IN THE GREAT HOGBACK, 5 MILES NORTH OF SAN JUAN RIVER, N. MEX.

THE FORMATIONS.

MANCOS SHALE.

The Mancos shale, the lowest formation exposed in the field, is a dark-gray to dark-drab marine shale. Its upper part contains a little sandstone, but it is a relatively homogeneous shale. The contact with the overlying Mesaverde group is gradational. No measurements of its thickness were made by the writers, but in the type region to the north it reaches 2,000 feet.

MESAVERDE GROUP.

The rocks of Mesaverde age in this field, though considerably thicker than those farther north, show the same tripartite character as in Mesa Verde National Park, the type locality. Recently Collier^a has named the formations, in ascending order, the Point Lookout sandstone, the Menefee formation, and the Cliff House sandstone. The Point Lookout is a marine sandstone with some shale, the Menefee formation is chiefly shale but includes some thick sandstone beds and contains both marine and fresh-water faunas and a flora, and the Cliff House consists of sandstone and shale. The thickness and character of these formations are best shown in the sections through the Great Hogback, in T. 29 N., R. 16 W., where it is cut by San Juan River and Chaco River. (See Pl. XIX.) Both are given below:

Section of Mesaverde group on San Juan River.

[Measured by Harvey Bassler.]

Lewis shale.

Mesaverde group:

Cliff House sandstone:		Ft.	in.
Sandstone, heavy, reddish brown to buff-----		4	
Shale, gray, sandy, with a few thin beds of sandstone-----		96	
Sandstone, massive, heavy bedded, reddish brown to buff, with thin layers of shale separating the sandstone beds-----		330	
Shale and sandstone, interbedded. Sandstone in thin layers and more abundant in upper part of unit; some layers ripple-marked. Both shale and sandstone gray-----		195	
Concealed; probably sandy shale-----		73	
Sandstone, soft, buff-----		8	
Shale, gray, sandy-----		11	
Sandstone, massive, pisolitic, dark brown on weathered surfaces, gray on fresh surface----		33	
		750	

^a Collier, A. J., Coal south of Mancos, Montezuma County, Colo.: U. S. Geol. Survey Bull. 691, p. 296, 1919.

Mesaverde group—Continued.

Menefee formation:

	Ft.	in.
Shale, gray, sandy-----	6	
Coal-----	7	6
Shale, sandy, brown, carbonaceous-----	20	
Bone-----		6
Shale, carbonaceous-----	2	6
Coal-----	1	
Shale, carbonaceous-----	1	
Coal-----	1	2
Shale, carbonaceous-----	4	
Coal-----		4
Shale, sandy, brown, carbonaceous-----	28	
Shale, soft, light colored, sandy-----	6	
Shale, sandy, brown, carbonaceous-----	12	
Shale containing 18 beds of sandstone. The sandstone layers range in thickness from 3 to 12 feet but average 5 feet-----	619	
Coal-----	1	2
Sandstone-----	15	
Shale-----	25	
Sandstone-----	7	
Shale-----	8	
Sandstone-----	30	
Shale-----	125	
Sandstone-----	35	
Shale-----	1	
Coal-----	1	4
Shale-----	1	2
Coal-----	1	
Shale and sandstone-----	10	
Coal-----	1	1
Shale-----	26	
Sandstone-----	12	
Shale-----	1	
Coal-----	1	
Shale-----	20	
Coal-----	1	1
Shale-----	2	6
Coal-----		10
Sandstone-----		1
Coal-----	2	2
Shale-----		2
Coal-----	2	1
Sandstone and shale-----	10	
Coal-----		2
Shale and sandstone-----	5	
Coal-----	1	2
Shale-----	21	

1,076

Mesaverde group—Continued.

Point Lookout sandstone:	Ft.	in.
Sandstone.....	32	
Shale, sandy.....	16	
Sandstone, with some layers of thin sandy shale.....	252	
	300	
Total Mesaverde group.....	2, 126	
Mancos shale.		

Section of Mesaverde group in T. 29 N., R. 16 W., where Chaco River cuts the Great Hogback.

[Measured by C. M. Bauer.]

Lewis shale.**Mesaverde group:**

Cliff House sandstone:	Ft.	in.
Shale and sandstone.....	60	
Sandstone, brown, pitted.....	18	
Shale, yellow, sandy.....	8	
Sandstone, light gray, pink in places.....	6	
Shale, blue and gray.....	5	
Sandstone, yellow, massive in upper part, carrying a few thin beds of shale; <i>Halymenites major</i> in lower part.....	318	
Shale, sandy, interbedded with yellowish sandstone layers, each 1 foot thick.....	133	
Sandstone, reddish brown, hard.....	10	
Shale, blue-gray.....	40	
Sandstone, massive, thin bedded on top, massive and nearly white below.....	25	
	623	

Menefee formation:

Shale, blue and gray, interbedded with lenses of buff sandstone. Shale beds are carbonaceous and contain thin streaks of coal.....	560	
Sandstone, massive, light gray.....	20	
Shale, gray; contains beds of sandstone 1 foot thick.....	80	
Sandstone, light gray, massive.....	12	
Shale, blue-gray, containing several carbonaceous streaks.....	92	
Sandstone, massive.....	20	
Shale, drab.....	5	
Coal.....	10	
Shale, carbonaceous, black.....	8	
Shale, blue-gray, containing carbonaceous streaks.....	246	
Sandstone, gray.....	10	
Shale, gray.....	8	
Coal.....	8	
Shale, gray.....	7	

Mesaverde group—Continued.**Menefee formation—Continued.**

Coal (moisture, 11 per cent; ash, 22 per cent)-----	Ft.	in.
	2	
Shale and sandstone, with thin beds of coal which are burned out-----	126	
	<u>1,132</u>	<u>10</u>

Point Lookout sandstone:

Sandstone, light buff and cream-colored, massive-----	67	
Sandstone, buff to brown, weathering red-brown-----	158	
Shale and sandstone, thin bedded, yellowish gray-----	20	
	<u>245</u>	

Total Mesaverde group-----	2,000	10
Mancos shale.		

LEWIS SHALE.

The Lewis shale is of marine origin and is very similar to the shale at Fort Lewis, Colo., the type locality.⁴ In Colorado this formation reaches a thickness of 2,000 feet, but in New Mexico it is thinner, being 1,100 feet thick 10 miles north of San Juan River, 475 feet thick on San Juan River, and decreasing further in thickness southward as far as Coal Creek, where it is 76 feet thick. It increases again to 103 feet on Meyers Creek and 140 feet on Escavada Wash. The Lewis shale has the same lithologic characteristics throughout the field. It is a greenish-gray sandy shale with local streaks of yellowish calcareous shale. On San Juan River it has also a prominent layer of buff limy concretions about 100 feet above its base.

PICTURED CLIFFS SANDSTONE.

Overlying the Lewis shale conformably is the Pictured Cliffs sandstone, of near-shore marine origin. There is no sharp line separating this sandstone from the underlying Lewis shale, but the shale becomes more sandy upward and passes into the sandstone by insensible gradations. Considered in a general way, the Pictured Cliffs sandstone is very different from the beds beneath. As the name indicates, it is a cliff-making sandstone, particularly on San Juan River immediately west of Fruitland, where it forms prominent copper-colored cliffs 20 to 40 feet high. Farther south it is a yellowish to light-gray or brown sandstone and not so massive. The formation is variable in thickness, owing in part to the nature of its boundaries. It is 200 feet thick near the State boundary, 187 feet 6 miles farther south, from 200 to 220 feet 6 miles north of San Juan River, 245 feet on the river, 49 feet on Brimhall Wash, 91 feet on Meyers Creek, and 70 feet on Escavada Wash.

⁴ Cross, Whitman, U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), 1899.



**A. COAL BED AT LOCATION 140, ON SAN JUAN RIVER HALF A MILE
SOUTHWEST OF FRUITLAND, N. MEX.**



**B. CHARACTERISTIC WEATHERING OF VARIABLE SANDSTONE OF THE FRUITLAND
FORMATION, MEYERS CREEK, N. MEX.**

FRUITLAND FORMATION.

Conformably above the Pictured Cliffs sandstone lie the brackish and fresh water beds of the coal-bearing Fruitland formation. The contact, like that between the Lewis shale and Pictured Cliffs sandstone, is gradational. The name Fruitland is derived from that of a settlement on San Juan River that is on the outcrop of this formation. The formation consists of sandstone, shale, and coal, very irregularly bedded. In constitution the various beds range from shale to sandstone with every conceivable intermediate phase of sandy shale and shaly sandstone. The marked variation both laterally and vertically is shown in many places by the unequal resistance to weathering and consequent production of fantastic assemblages of pillars, knobs, "mushroom rocks," and other forms. (See Pls. XX and XXI.) This irregularity is most marked in the gray-white sandstone and gray sandy shale, but it affects to some degree the coal beds also. Nevertheless, although the coal beds are lenticular, they are much more persistent than the individual sandstone and shale layers with which they are associated. Some of the coal beds have been traced along their outcrops with considerable certainty for 15 or 20 miles and are of sufficient thickness and good enough quality throughout to be of commercial value when transportation facilities become available. The coal beds are distributed throughout the formation but are more abundant and generally thicker in its lower portion. They are described in detail in the later pages of this report. The Fruitland formation is further characterized by the presence of large concretions of iron carbonate which weather dark brown or black. Many of these concretions have been converted by veins of crystallized barite into large septaria. The Fruitland formation is more sandy than the lower part of the Kirtland shale, from which it is separated by a gradational zone marked in many places by sandstone lenses apparently of river origin. The thickness of the Fruitland formation varies somewhat in this field, ranging from 196 to 415 feet. It is thicker in the northern part of the area than in the southern part. (See sections, Pl. XXII.) The following sections of the Fruitland formation are given to illustrate its character and the thickness and position of the coal beds:

Section of the Fruitland formation on divide between La Plata and San Juan rivers.

Kirtland shale.	
Fruitland formation:	
Shale and sandstone.....	Ft. in. 80
Sandstone.....	5
Shale.....	20
Sandstone.....	10

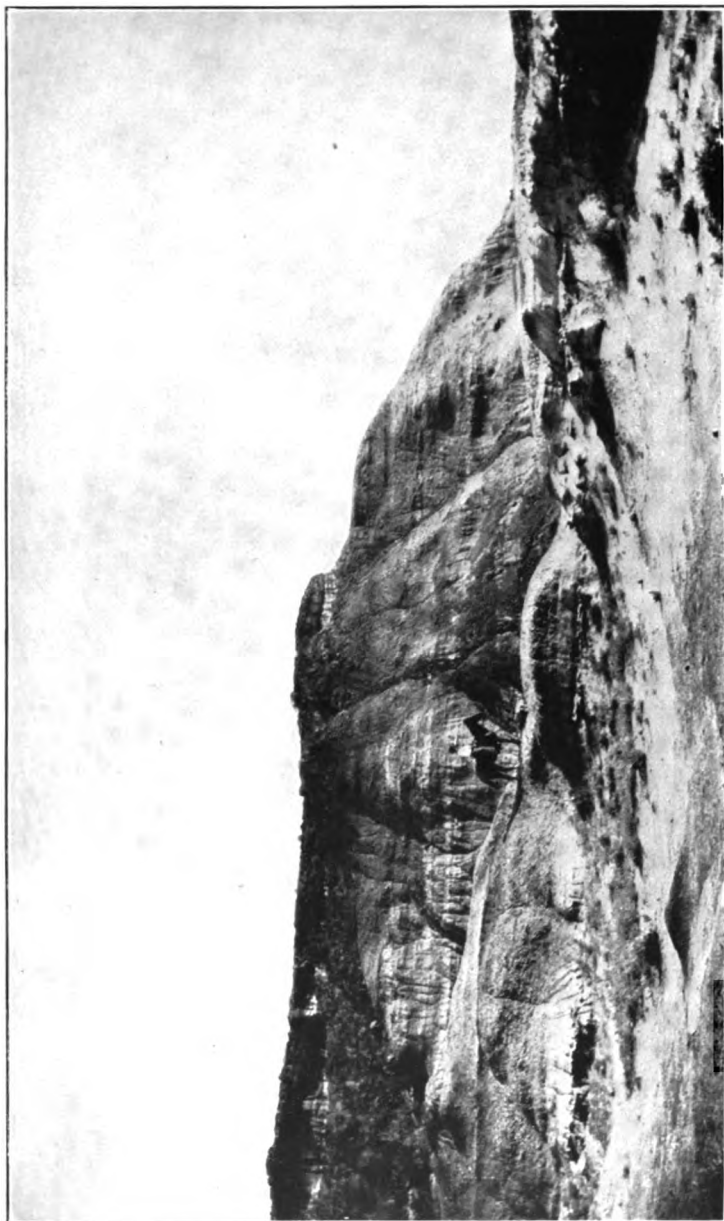
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Fruitland formation—Continued.		Ft.	in.
Shale, carbonaceous in part	-----	80	
Coal, high in ash	-----	1	6
Shale, carbonaceous	-----	2	6
Coal	-----		3
Shale, carbonaceous	-----		6
Coal	-----		5
Shale, carbonaceous	-----	2	3
Coal	-----	1	2
Shale, carbonaceous	-----		10
Coal	-----		7
Shale, carbonaceous	-----		1
Coal	-----		2
Shale, carbonaceous	-----		9
Coal	-----		7
Shale, carbonaceous	-----	3	
Coal	-----		6
Shale, carbonaceous in part	-----	75	
Coal, with many shale and bone partings (see sec. 32, Pl. XXVI, for details)	-----	14	2
Shale, sandstone, and some concealed intervals	-----	125	
Coal	-----	2	6
Pictured Cliffs sandstone.	-----		
		426	110

Section of Fruitland formation on San Juan River.

Kirtland shale.

Fruitland formation:		Ft.	in.
Sandstone, gray, fine grained, irregularly bedded	-----	7	
Shale, gray to black; contains fragments of carbonized wood and is streaked with limonite	-----	8	
Shale, light gray to drab, with limonite streaks; sandy in lower portion	-----	11	
Shale, very sandy, light gray to buff	-----	12	
Sandstone, buff, friable; contains concretions of light-gray fine-grained sandstone	-----	15	
Shale, drab, sandy	-----	1	
Shale, brown, carbonaceous; contains plant fragments	-----	2	
Shale, light gray, very sandy, with streaks of pearl-gray calcareous shale and drab platy concretions	-----	14	
Shale, dark brown, carbonaceous; contains plant fragments and gypsum in small flakes	-----	7	
Shale, light gray to drab	-----	10	
Sandstone, platy, fine grained, very light greenish gray	-----	20	
Shale, light gray, sandy, locally carbonaceous	-----	15	
Shale, dark brown, carbonaceous; contains thin lenses of bone	-----	6	
Sandstone, very light gray, fine grained, carbonaceous	-----	18	
Shale, gray to drab, with carbonaceous bands which are burned locally (probably coal beds elsewhere)	-----	30	



PART OF THE FRUITLAND FORMATION NEAR HUNTER'S STORE, IN T. 24 N., R. 13 W., N. MEX.

Fruitland formation—Continued.

	Ft.	in.
Sandstone, light gray, fine grained; contains lenses of carbonaceous shale; sandstone is gray to white, cross-bedded, and locally stained brown.....	25	
Shale, brown to black, carbonaceous.....	3	
Coal.....	1	8
Shale, brown, sandy.....		6
Bone.....		5
Coal, good.....	1	
Shale, buff, sandy.....		5
Coal and bone in thin lenses.....		9
Shale, carbonaceous, black.....		1
Coal; contains resin.....	3	7
Shale, sandy, gray and carbonaceous in places.....		3
Coal, impure.....		4
Shale, gray, sandy.....		1
Bone.....		6
Shale, gray, sandy.....		1
Coal, impure.....	1	4
Shale, gray, sandy.....		3
Coal, impure.....	2	11
Bone.....		4
Shale, gray, sandy.....		1
Bone.....		5
Shale, carbonaceous.....		3
Shale, clayey and carbonaceous.....	2	3
Bone.....		3
Shale, brown.....	5	
Coal.....		4
Shale, sandy, brown.....	5	
Shale, light gray, sandy.....	2	
Sandstone, greenish, cross-bedded.....	3	6
Shale, brown.....	1	
Sandstone, nearly white.....	6	
Coal.....		6
Sandstone.....	1	
Coal.....		6
Pictured Cliffs sandstone.....	246	6½

Section of Fruitland formation on Cottonwood Arroyo.

Kirtland shale.

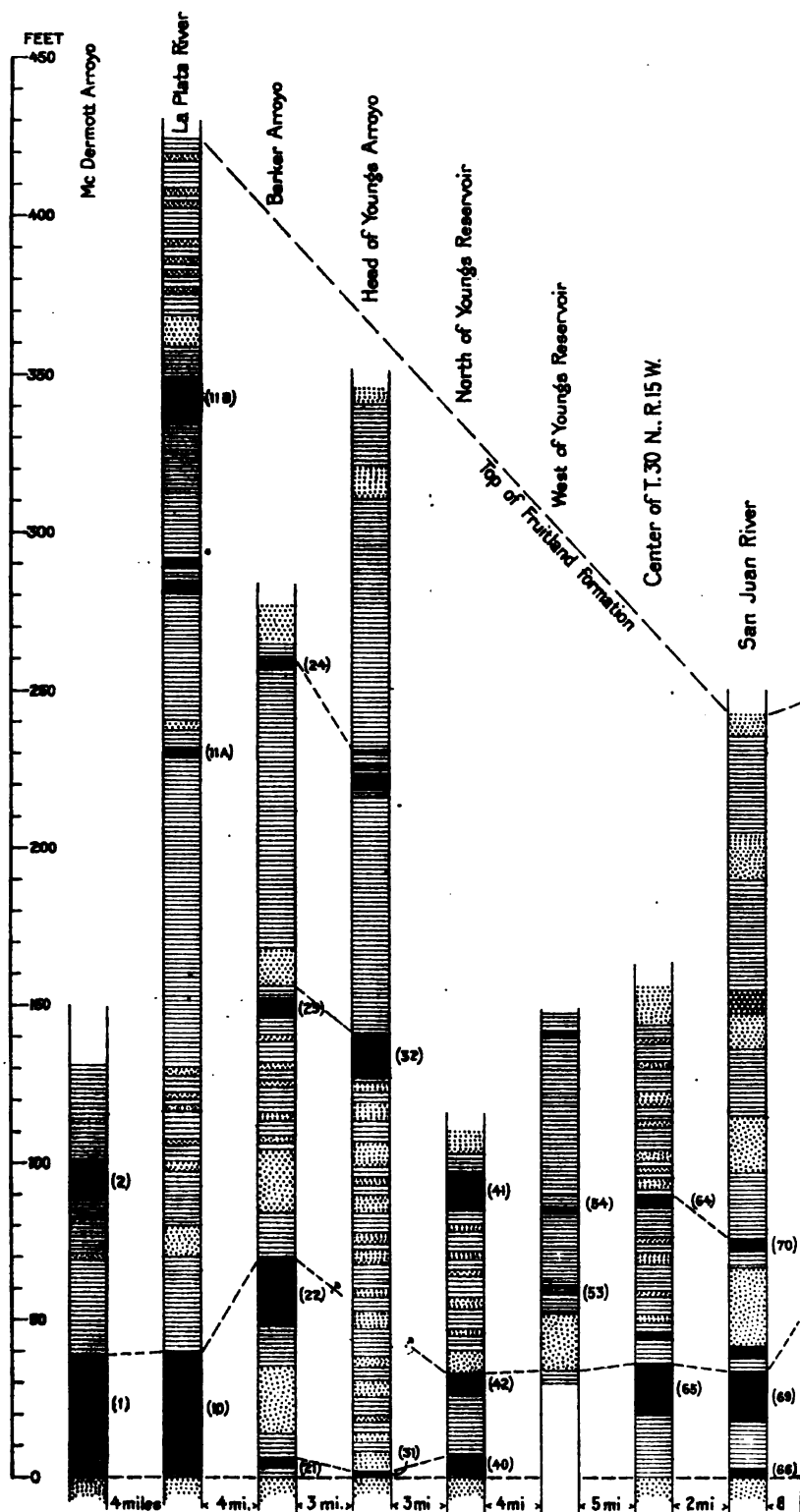
Fruitland formation:	Ft.	in.
Sandstone, brown, platy.....	13	
Shale, sandy, gray.....	31	6
Sandstone, brown, cross-bedded, concretionary.....	5	
Sandstone; contains concretions of iron carbonate.....	4	
Sandstone, irregularly bedded and unequally indurated.....	8	
Shale, gray, sandy, concretionary.....	28	
Coal.....		10
Shale, sandy.....		1
Coal.....		5
Sandstone, carbonaceous.....		1

Fruitland formation—Continued.		Ft.	in.
Coal	-----		6
Sandstone, carbonaceous	-----		6
Coal	-----	2	2
Shale, carbonaceous	-----	1	
Shale, gray	-----	15	
Sandstone, buff to gray, cliff-forming	-----	20	
Shale, carbonaceous	-----		10
Shale, gray	-----	35	
Sandstone, gray, easily eroded	-----	11	6
Coal	-----	1	7
Sandstone	-----		3
Coal	-----	2	1
Shale, carbonaceous, brown and gray	-----	12	6
Sandstone, gray; contains lime concretions	-----	4	
Shale, sandy	-----	8	
Shale, brown, carbonaceous	-----		10
Bone	-----		3
Coal, impure	-----		3
Sandstone	-----		1
Coal	-----	3	8
Bone	-----		2
Coal	-----		11
Shale, carbonaceous	-----	6	
Sandstone, nearly white, soft, cross-bedded, streaked with limonite	-----	15	
Shale, gray, sandy	-----	2	
Coal, impure	-----	1	7
Ash (from burned coal)	-----		8
Shale, gray	-----	7	6
Ash (from burned coal)	-----	1	
Shale, bluish gray, sandy	-----	16	
Sandstone, nearly white, soft; contains streaks of limonite $\frac{1}{4}$ inch thick and in places irregular masses of brown cross-bedded sandstone	-----	25	
Coal	-----		6
Shale, blue-gray, sandy	-----	15	9
Sandstone, shaly in places, light colored, platy	-----	12	
Shale, carbonaceous	-----		4
Coal	-----		8
Shale, sandy	-----	5	4
Coal	-----	2	7
Shale	-----	1	5
Bone	-----		5
Shale, sandy, carbonaceous	-----	3	
Pictured Cliffs sandstone.	-----		
		323	9

Section of Fruitland formation on north fork of Meyers Creek.

Kirtland shale.

Fruitland formation:		Ft.	in.
Sandstone, soft gray at base, capped by hard brown coarse-grained layers	-----	4	
Shale, gray, sandy, streaked with yellow; occasional lenses of sandstone containing iron concretions	-----	42	



COLUMNAR SECTIONS OF THE FRUITLAND FORMATION

Fruitland formation—Continued.

	Ft.	in.
Shale, black, carbonaceous.....		6
Shale, gray, sandy, banded with yellow, locally a soft gray sandstone, concretionary.....	10	
Shale, light gray, sandy.....	25	
Shale, dark brown, carbonaceous.....		8
Shale, gray, with iron concretions and barite.....	5	3
Shale, black, carbonaceous.....		6
Sandstone, yellow, clayey.....		4
Shale, dark brown, carbonaceous.....	1	6
Sandstone, clayey, gray, streaked with yellow; contains brown platy concretions of coarser sandstone and some aragonite concretions.....	12	6
Coal.....		2
Sandstone, black, carbonaceous.....		6
Bone.....	1	
Shale, sandy; contains brown and gray lenses of sandstone and ferruginous concretions with barite and lenses of carbonaceous shale.....	32	6
Sandstone, soft, gray with brown streaks, cross-bedded and platy at top.....	6	
Shale, brown, carbonaceous, locally sandy.....	3	3
Coal, impure.....		11
Bone.....		4
Coal, impure.....	1	2
Bone, sandy.....		3
Coal.....		4
Bone, sandy; contains lumps of resin.....		1
Coal, impure, with resin.....	1	7
Shale, gray and yellow, sandy.....	10	6
Shale, gray, sandy, and lenses of yellow sandstone, concretionary.....	10	
Sandstone, light gray, fine grained, unequally indurated; contains dark-brown sandstone concretions.....	7	
Shale, dark brown, carbonaceous.....		6
Shale, dark gray; contains iron concretions locally.....	5	
Sandstone, light gray, cross-bedded; contains iron concretions with barite; grades laterally into shale.....	7	6
Bone.....		6
Coal.....		7
Bone.....		5
Coal, impure.....		2
Shale, black, carbonaceous.....	2	10
Coal, impure.....		5
Bone, sandy.....		1
Pictured Cliffs sandstone.....		
	196	1

KIRTLAND SHALE.

The Kirtland shale, named for a post office on San Juan River, lies conformably upon the Fruitland formation. It is composed mostly of gray shale, with some brown and black carbonaceous layers, bluish, greenish, and yellowish shales, easily weathering gray-white sand-

stone, and the brown resistant sandstone of the Farmington member described below. At some points thin beds of purple shale are present near the top of the formation. Barite occurs in concretions and veins in the shales. The Kirtland shale is readily affected by weathering and gives rise to extensive badlands. The formation, so far as known, is of fresh-water origin. It ranges in thickness from 700 feet on Escavada Wash to 950 feet in northern San Juan County and to 1,180 feet on Hunter Wash. It is divided typically into three portions—a lower shale, a middle sandy part named the Farmington sandstone member, and an upper shale.

The sandstone member is well shown in the prominent bluff on San Juan River near Farmington, which it is 455 feet thick. Toward the north this member thickens somewhat, but toward the south it is gradually replaced by shale until on the head of Coal Creek the member disappears as a mappable unit. Still farther south it is represented only by isolated sandstone lenses in the Kirtland shale. The individual sandstone lenses that make up the Farmington member are irregular in thickness, cross-bedded, and composed almost invariably of two parts—at the base an easily eroded yellowish sandstone carrying clay pellets of various sizes and in some lenses sandstone pebbles similar to the matrix and as much as 4 inches in diameter, and above a markedly resistant brownish sandstone, whose upper portion is commonly a dark chocolate-brown on the exposed surface and dark gray on the fresh surface. An individual lens will usually have a maximum thickness of 20 feet and a length of several hundred yards.

The upper part of the Kirtland shale is a thin unit, ranging from 40 to 110 feet in thickness, and is composed of shale and easily weathered gray-white sandstone lenses, very similar to the lower shale unit but carrying in many places relatively high-colored layers of yellow, blue-gray, and purple shale. Its persistence throughout the field is believed to signify a lack of erosion and consequently a small or even no time interval between the deposition of the Kirtland shale and that of the Ojo Alamo sandstone.^{4a}

OJO ALAMO SANDSTONE.

The Ojo Alamo sandstone,⁵ composed of white, gray, or brown conglomerate sandstone with lenses of soft whitish sandstone and gray or drab shale, overlies the Kirtland shale with apparent conformity. The contact is at many places sharp and well marked, but at other places it is difficult to determine just exactly where in the

^{4a} See footnote ^{2a}, p. 173.

⁵ For a more complete description of this sandstone see Bauer, C. M., *Stratigraphy of a part of the Chaco River valley*: U. S. Geol. Survey Prof. Paper 98, pp. 275-276, 1916.

section the formation boundary lies. There does not seem to have been any considerable amount of erosion before the Ojo Alamo sandstone was laid down in the area covered by this report. The Ojo Alamo sandstone is of fluvial origin. In southern San Juan County it ranges from 60 to 129 feet in thickness. Farther north it increases to nearly 400 feet.

In Colorado the volcanic Animas formation lies above the "Laramie formation" of older authors, which is equivalent to the Pictured Cliffs sandstone, Fruitland formation, and Kirtland shale, inclusive. The relation of the Animas formation to the Ojo Alamo sandstone is not yet known.^{5a}

PUERCO AND TORREJON FORMATIONS.

The Puerco and Torrejon formations are very similar lithologically, and their respective faunas are limited to a few narrow but widely separated zones. No mappable plane of separation between them has yet been recognized, and the formations are therefore mapped and considered together. The Puerco formation everywhere rests with uneven base on the Ojo Alamo, and it is believed that the contact is an unconformity, though the amount of erosion was not great.

At the head of Escavada Wash the lower 250 feet of beds is composed of lenticular light and dark gray shales with bands of purplish, bluish, black, and rarely claret-colored shale and of soft gray-white sandstone. This part carries Puerco fossils in its lower strata. It is overlain by 500 feet of lenticular cream-colored to yellow and brown, more indurated sandstone with reddish-brown concretions. The sandstone beds are separated by greenish-gray and lead-gray shales and some soft white sandstone. Fossils are very scarce. The upper 450 feet of beds includes very dark slate-colored shale with two prominent and several fainter red bands and also soft gray-white sandstone. This upper part contains Torrejon fossils.

Near Ojo Alamo the Puerco and Torrejon are only 390 feet thick. The lower 140 feet is composed of much the same material as the lower part on Escavada Wash and carries Puerco fossils near the base. The overlying 250 feet consists of gray shale with bands of brown, greenish-gray, and dark slate-colored shale, soft gray-white sandstone, and some layers of more resistant yellow and brown sand-

^{5a} Field work done by the junior author in 1920 has shown that a thinning wedge of the Animas formation extends as far south as San Juan River. The Ojo Alamo sandstone extends northward upon the Animas wedge as far as T. 31 N., R. 13 W., where Puerco or Torrejon beds rest directly on Animas beds. The base of the Animas wedge in New Mexico is apparently conformable, though in Colorado it is clearly unconformable on the Kirtland shale. Southeast of Escavada Wash the Ojo Alamo sandstone is also clearly unconformable on Kirtland shale, and it is likely that both Animas and Ojo Alamo belong with the later rather than with the earlier beds. A full discussion of these new data will be given in a paper now in preparation.

stone. This upper part bears Torrejon fossils. Layers and concretions of dark-green to black manganitic sandstone and concretions of barite occur abundantly in the group, also thin layers of a dense cream-colored flintlike material that is full of plant stems. Silicified wood is common.

On San Juan River at and above Farmington* the Ojo Alamo sandstone is overlain by a succession of white to buff, in places rusty-brown sandstones which carry lenses of pebbles and are separated by light-gray, dark-gray, and brown-banded shales. Layers of fine green sandstone and a dense flintlike material are common, as is also silicified wood. The material in many respects is different from that farther south and contains very few fossils. By its position in the section and the fact that it dips eastward under beds containing Torrejon fossils, it is shown to belong to either the Torrejon or the Puerco formation, although direct connection with the southern exposures can not be traced. In the country north of San Juan River the Puerco and Torrejon formations have much the same character as on the river and reach a thickness of 1,400 feet.

The fossils of the Puerco formation and the Torrejon formation differ enough to indicate the lapse of a long period of time during which there may have been erosion, now represented by an unconformity, but there is little indication on the ground of such a break.

FORMATION UNDETERMINED.

In the southern part of San Juan County the beds containing the Torrejon fauna are overlain by a banded deposit, 250 feet thick, of dove-colored shale, lighter-gray sandy shale, and soft white sandstone. A few reddish bands occur near the top, and rarely dark shale is present. One or two more resistant light-gray sandstone lenses carrying pebbles were observed. No fossils were found. The lower boundary of this unit is a clean-cut line with marked irregularities. In its lithology and position the unit suggests strongly the beds in southern Colorado recently described by Granger[†] as the Tiffany beds. These beds at the type locality carry a fauna intermediate in character between those of the Torrejon and Wasatch formations and reach a thickness of at least 300 feet.

In the map by the senior author published as Plate LXIV of United States Geological Survey Professional Paper 98 these beds in the district southeast of Chico Springs are shown as within the

* The rocks now referred to the Ojo Alamo sandstone and overlying beds on San Juan River were assigned by the senior author to the Wasatch formation on a map published as Plate 64, U. S. Geol. Survey Prof. Paper 98, 1916. Later and more detailed work farther east has shown that this assignment was in error. It is probable that no true Wasatch beds occur in the territory shown on that map.

[†] Granger, Walter, Notes on Paleocene and lower Eocene mammal horizons of northern New Mexico and southern Colorado: Am. Mus. Nat. Hist. Bull., vol. 27, pp. 821-830, 1917.

Wasatch formation, but later work has suggested the desirability of separating them from the true Wasatch of the region.

WASATCH FORMATION.

At the southeastern extremity of the field the highest rocks observed comprise a very massive, cliff-forming copper-red basal sandstone with lenses of pebbles which is about 50 feet thick, overlain by 150 feet of light-gray and red shales and soft white sandstone, overlain in turn by another prominent cliff-forming sandstone similar to the first. The basal contact of the lower sandstone is not noticeably irregular. No fossils were observed in these beds. The Wasatch formation farther east has been described by different observers as consisting of a basal conglomeratic sandstone overlain by a succession of shales and sandstones with marked coloring. The writers have not traced the horizons, but there would seem to be little doubt that the rocks at the head of Escavada Wash are continuous with the *Coryphodon*-bearing Wasatch of the southeastern part of the San Juan Basin.

AGE OF THE FORMATIONS.*

The Mancos shale typically contains invertebrate faunas of Colorado age in the older part and of Montana age in the younger part. Only Montana species were found in the small area of upper Mancos shale examined in this field.

The Mesaverde group has a flora and an invertebrate fauna of Montana age.

The Lewis shale and the Pictured Cliffs sandstone likewise contain invertebrate faunas of Montana age, though with elements not known in the latest Montana faunas, such as that of the typical Fox Hills sandstone.

The Fruitland formation and Kirtland shale contain a homogeneous flora and vertebrate and invertebrate faunas. The flora is of Montana age and closely related to that of the Mesaverde and allied formations of the region. The vertebrate fauna is entirely reptilian and of types known elsewhere only in beds of Montana age. The invertebrate fauna consists of fresh and brackish water forms, in the main of types known elsewhere only in post-Montana beds, though several of the brackish-water species occur only in beds of Montana age and several range from Montana beds into post-Montana beds. It seems most logical, in the light of present knowledge, to consider the Fruitland formation and Kirtland shale as of late Montana age.

The Pictured Cliffs sandstone, the Fruitland formation, and the Kirtland shale together make up the "Laramie formation" of the

* For references to literature see footnote, p. 161.

older works dealing with the San Juan Basin. The Ojo Alamo sandstone was also included by some authors. There is still considerable uncertainty as to what part, if any, of the section in San Juan County is equivalent to the typical Laramie of northeastern Colorado.

The Ojo Alamo sandstone has furnished a few poor specimens of plants of little value in correlation and has supplied evidence of a considerable dinosaurian fauna. The only specimen complete enough to identify occurs also in the Kirtland shale. Other specimens are definite enough, however, to be recognized as unlike any known post-Montana species.⁹ The abrupt appearance of conglomerate lenses and coarse sandstone in the Ojo Alamo, above the Kirtland shale, has been interpreted as marking a great change in conditions of deposition, considerable lapse of time, and therefore a closer relation of the Ojo Alamo to the later formations than to the earlier, particularly as such a condition exists elsewhere in the general region.¹⁰ However, there is little evidence of an erosional break at the base of the Ojo Alamo sandstone—the persistent thin upper shale of the Kirtland does not show it—and no other evidence of a time break in the succession except the change in lithology. The apparent relationship of the fauna would place the deposition of the Ojo Alamo sandstone in Montana time, though it is not conclusive. This view demands a hiatus between the sandstone and the overlying Puerco formation to account for the interval represented elsewhere by the Laramie formation, which is of post-Montana age but still within the Cretaceous.^{10a}

The Puerco and Torrejon formations have furnished a small flora that is interpreted as of Tertiary age and a considerable vertebrate fauna. This fauna consists chiefly of primitive mammals and turtles but no dinosaurs and is universally regarded as of early Tertiary age. The base of the Puerco formation lies on an irregular surface that shows the effect of some erosion, though not enough in this field to indicate by itself a long time interval. The Puerco elsewhere is said to overlap older formations, and certainly its fauna has nothing in common with those of older formations. The fauna of the Torrejon is of the same type as that of the Puerco but is distinct from it and definitely advanced toward modern mammals.

The Tiffany beds of Sinclair and Granger at their type locality carry a fauna intermediate between that of the Torrejon and Wasatch. The beds in this field that may be equivalent to them occupy the same stratigraphic position and are similar in lithology but yielded no fossils by which to verify the correlation.

⁹ Gilmore, C. W., personal communication.

¹⁰ Lee, W. T., and Knowlton, F. H., *Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico*: U. S. Geol. Survey Prof. Paper 101, p. 55, 1917.

^{10a} See footnote ^{9a}, p. 173.

The highest rocks in this field are correlated with the Wasatch of the region on the basis of stratigraphic position and lithologic similarity.

COAL.

DISTRIBUTION.

Coal occurs in the Menefee formation of the Mesaverde group and in the Fruitland formation. There are also local deposits of lignitic material at the base of the Puerco formation, such as that prospected just south of Farmington, and reports are current locally of coal in higher formations. The writer studied in detail the coal of the Menefee formation only in a small area just north of San Juan River, and most of the following description will therefore be devoted to the coal of the Fruitland formation. The coaly material of the younger formations is of very little value in this general region and may be dismissed from consideration.

The coal beds of the Menefee formation are in two groups—one near the top, the other near the bottom of the formation. The beds are lenticular and are variable in purity and thickness. Most of them are relatively thin, but at some places a considerable thickness of minable coal is present.

The coal beds of the Fruitland formation are scattered throughout the formation but are thicker and more persistent in the lower part. The thickest beds lie north of San Juan River, though the total amount of coal is large in some places south of that stream, notably at the mouth of Klaychen Arroyo. Locally extensive burning of the coal beds has taken place and their former positions are marked by red baked shale and clinker. The very thick coal bed low in the Fruitland formation in northern San Juan County has been correlated with that formerly mined at Carbonero Junction, near Durango, Colo.,¹¹ but extensive correlations are doubtful south of the San Juan. In the extreme southern part of the field the coal beds decrease in number, thickness, and extent, and the coal is of poorer quality than it is in the northern part. Owing to this tendency to deteriorate southward, the coal on Escavada Wash possesses very little economic value.

CHARACTER.

PHYSICAL PROPERTIES.

The coals of the Menefee and Fruitland formations are very similar in character. Both are black with a bright luster and are hard and brittle and break readily in handling. They check and break

¹¹ Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 816, pp. 392-398, 1906.

on exposure to the air and sun but with some protection may be stored almost indefinitely. The suitability for storage is an important feature in estimating the value of a coal. Resistance to deterioration on exposure is the chief difference between bituminous and subbituminous coal.¹² The chemical differences, though well marked if the two classes are considered as entities, are small between many high-grade subbituminous coals and low-ranking bituminous coals. Subbituminous coal, owing to its larger percentage of moisture, breaks down or "slacks" readily on exposure to weather and must be protected or it will disintegrate to a dust, whereas bituminous coal is relatively unaffected on exposure. South of San Juan River all the coal of the Fruitland formation and that of the Menefee formation away from the Hogback is subbituminous. In the Hogback and north of the San Juan the coal of the Menefee formation is all bituminous. North of the San Juan the coals of the Fruitland formation pass from subbituminous to bituminous in rank, but they are of somewhat poorer quality than the older coals.

All the coals of this field burn to a gray ash without clinker. Nothing is known of their coking qualities, though the higher-grade coals a little farther north, in Colorado, are coked and used at the smelter at Durango.

The coal of the Fruitland formation at many localities contains a considerable amount of the fossil resin wheelerite,¹³ in the form of clear brown or yellow grains about the size of a pea. It has been mistaken for sulphur, though in coal sulphur does not occur as such, but in combination with the coal substance or with iron as the brassy minerals marcasite and pyrite (fool's gold). These minerals were not seen in this field.

CHEMICAL CHARACTER.

An analysis of a coal sheds much light on its value, though various properties not indicated by the analysis are important also—for example, resistance to exposure and suitability for storage and shipment without deterioration, behavior in handling and resistance to breakage and production of fine coal, capacity for coking, fusibility of the ash, and presence or absence of clinker. Yet much may be learned of a coal from a knowledge of the percentages of moisture, volatile matter (gases), fixed carbon, ash, and sulphur determined in what is known as a "proximate analysis," the percentages of the actual elements composing the coal determined in an "ultimate analysis," and

¹² For a discussion of the classification of coals see Campbell, M. R., *The coal fields of the United States—General introduction*: U. S. Geol. Survey Prof. Paper 100, pp. 3-10, 1917 (Prof. Paper 100-A).

¹³ U. S. Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 630-631, 1875.

the heating efficiency expressed in calories or British thermal units.¹⁴ Inasmuch as coal owes its economic value primarily to its ability to produce heat, the heating efficiency is perhaps the most important. As it is in a sense resultant of the chemical composition, the sum of all the other factors of the analysis, it is used (p. 181) as the basis of comparison of the coals of this field with those of other fields.

In the production of heat the volatile matter and the fixed carbon are to be considered as the valuable constituents, and the moisture, ash, and sulphur as injurious constituents. Moisture and ash are inert, absorb part of the heat produced by other constituents, and replace heat-forming substances in such proportion as they are present. Sulphur produces in burning objectionable and harmful gases.

The table on pages 183-187 shows analyses made by the Bureau of Mines of 15 samples of coal from San Juan County and 15 from other fields for comparison. Twelve of the samples from San Juan County were obtained from local mines of the drift type and three from open pits representing the freshest and least-altered coal obtainable. The small amount of adherent moisture—that is, moisture which may be removed by drying—as well as of total water in most of the samples is probably due to the aridity of the climate and consequent low position of the water table during most of the year. The absence of water in and over the coal, however, has the effect of permitting freer access of air and the consequent weathering of the coal much farther back from the outcrop than where the beds are moist the year round. On weathering there is a loss of volatile matter and of heating value, as is shown by the analyses of samples 17750 and 29006, the former from a point 100 feet from the mine mouth, the latter 350 feet from the mine mouth.

All these samples were obtained by the regulation method prescribed by the Geological Survey and the Bureau of Mines, which "involves selecting a representative face of the bed to be sampled; cleaning the face, making a cut across it from roof to floor, and rejecting or including impurities according as these are included or excluded in mining operations; reducing the gross sample, by crushing and quartering, to about 4 pounds; and immediately sealing the sample in an airtight container for shipment to the laboratory."¹⁵

The four forms of analysis given for each sample are not different determinations but merely four forms of one analysis. Form A is the analysis of the coal exactly as it comes from the bed. Owing to the fact that the original moisture content of a sample is largely a matter of accident and depends partly on the amount of water in and around the place from which it came, it is best for comparisons to use Form B, which is the analysis of the sample air dried under

¹⁴ A calorie is the amount of heat required to raise the temperature of a gram of pure water 1° centigrade at or near 4° C. A British thermal unit is the amount of heat required to raise the temperature of a pound of water 1° Fahrenheit at or near 39° F.

¹⁵ Bur. Mines Bull. 22, p. 8, 1913.

uniform conditions. Form C is the analysis of the sample after all moisture has been theoretically eliminated. Form D is also computed and is the analysis of the sample after all moisture and ash have been theoretically removed. Forms C and D are useful chiefly to engineers.

Five of the analyses represent the coal of the Menefee formation of this field, collected at locations 104 and 548 and at points near Tiznatzin and Putnam (Pueblo Bonito). (See Pl. XVI.) The coal, as represented by analyses 17750 and 29006, is very low in ash and sulphur and relatively high in heating value. Compared with coal mined at Durango, on the north side of the San Juan Basin (analysis 14772), it is lower in fixed carbon and heating value and higher in moisture; compared with that mined at Gallup, on the south side of the basin (analysis 19135), it is higher in heating value and lower in ash. The analyses of samples collected in southern San Juan County show that the coal there is not so good as that in the northern part, being relatively high in ash and sulphur and, as mined, in moisture. It is lower in heating value and about equal to that mined at Gallup.

Ten of the analyses represent the coal of the Fruitland formation, collected at locations 9, 10, 58, 61, 67, 69, 301, and 419. (See maps.) The coal of this formation is low in moisture and sulphur. Two samples show a high sulphur content, which is due possibly to the accidental inclusion of coal with adhering powder residue but possibly also to some local variation in the coal. In ash this coal is uniformly higher than the older coal. The samples collected in the northern part of the field are as high in heating value as the older coal of the same area and higher than the older coal of the southern part. The samples collected in southern San Juan County are about equal to the Gallup coal, though as they come from shallow open pits they may not represent as high-grade coal as that under thicker cover at the same localities.

At present the coals of this field are mined only for local use and consequently come into competition only with that shipped in from Durango, Colo. Should better railroad communication with the north or south, or both, become available the question of competition with other coals of Colorado and New Mexico would become of great importance to one attempting the development of mines in the San Juan field. If a railroad were built into the field from the south any coal mined here would have to compete directly with coal mined in the vicinity of Gallup and indirectly with that of the Raton field, in Colfax County. If better railroad connection were made with the main line of the Denver & Rio Grande Railroad on the north, the local coal would have to compete with the Colorado coals mined near Porter and Hesperus, La Plata County; near Somerset and Crested

Butte, Gunnison County; and near Newcastle and Sunlight, Garfield County; and with the Utah coals mined at Thompson, Sunnyside, and Castlegate. If facilities for shipping coal to the East were improved the local coal would have to compete with coal of the Trinidad and Canon City fields, east of the mountains, and possibly with the subbituminous coal of the Boulder region, which is an important factor in the Denver market. Analyses of representative samples from all these fields are given for comparison on pages 185-187, but the sample from Crested Butte does not represent the highest-ranking coal of that field, for even anthracite is found there.

Other elements entering into value being disregarded, it is of interest to compare the coals of San Juan County and other fields on the basis of their heating value (1) as they come from the mine, (2) air dried, (3) with the deleterious moisture and ash theoretically removed. The first condition is perhaps the nearest to the average coal actually purchased by the consumer; the second avoids the accidental differences due to the local conditions in the mine, drying in storage and shipment, etc.; the third shows how much of the difference in heating value is really due to difference in the pure coal substance. In the following table, for simplicity in comparison, the best coal of San Juan County is taken as having a value of 100, and the heating values of the other coals are expressed in proportionate figures:

Comparative heating values of coals of San Juan County and other fields.

	Analy- sis No. ^a	As mined.		Air-dried.		Ash and mois- ture free.	
		British thermal units.	Ratio.	British thermal units.	Ratio.	British thermal units.	Ratio.
SAN JUAN COUNTY.							
1. Menefee formation, northern part.....	29006	12,010	100	12,270	100	14,020	100
2. Fruitland formation, northern part, bitu- minous.....	(b)	11,720	98	12,060	98	14,380	103
3. Fruitland formation, northern part, sub- bituminous.....	(c)	11,140	93	11,570	94	13,960	99
4. Fruitland formation, southern part.....	(d)	10,360	86	11,020	90	13,680	98
5. Menefee formation, southern part.....	(e)	10,130	83	11,090	90	13,300	95
OTHER FIELDS.							
6. Durango, Colo.....	14772	13,710	114	13,990	114	15,220	109
7. Crested Butte, Colo.....	7983	13,430	112	13,620	111	14,960	107
8. Castlegate, Utah.....	19880	13,060	109	13,200	108	14,430	103
9. Trinidad, Colo.....	14060	13,000	108	13,080	107	15,270	109
10. Hesperus, Colo.....	14775	12,670	106	13,170	108	14,550	104
11. Koehler, N. Mex.....	12338	12,620	105	12,870	105	14,960	107
12. Sunnyside, Utah.....	12630	12,620	105	12,810	104	14,490	103
13. New Castle, Colo.....	12327	12,620	105	13,090	107	14,400	103
14. Somerset, Colo.....	12324	12,430	104	12,650	103	14,600	104
15. Sunlight, Colo.....	4034	12,420	103	12,810	104	14,470	103
16. Thompson, Utah.....	17577	11,720	98	11,950	97	14,210	101
17. Canon City, Colo.....	13395	11,420	95	12,120	99	13,710	98
18. Gallup, N. Mex.....	19135	11,100	92	11,770	96	13,940	99
19. Lafayette, Colo.....	15165	9,940	83	11,080	90	13,120	94

^a See table of analyses on pp. 185-187.

^b Average of analyses 17749, 29249, 29250.

^c Average of analyses 22026, 23023, 2464, 22508, 22509.

^d Average of analyses 22635, 22807.

^e Average of analyses 3811, 23003, 23004.

From the figures given under "Ash and moisture free" it is apparent that so far as heating power is concerned the best coal intrinsically with which the San Juan coal may compete is that from Trinidad, Colo., but on account of the heavy percentage of ash which that coal contains it is not the most efficient coal as it reaches the consumer. The best coal as it reaches the consumer is that from Durango—in other words, the San Juan coal has its greatest competitor near home.

In the table given above the relative values of these coals are expressed in percentages, but if put on a strict money basis the comparative values might be expressed as follows: If the consumer paid \$5 for a ton of the best San Juan coal, delivered as mined, he could afford to pay the following prices per ton for the other coals listed above, as he would receive the same heating value per dollar.

Comparative heating value of San Juan and other coals expressed in value per ton.

1_____	\$5.00	6_____	\$5.70	11_____	\$5.25	16_____	\$4.90
2_____	4.80	7_____	5.60	12_____	5.25	17_____	4.75
3_____	4.65	8_____	5.45	13_____	5.25	18_____	4.60
4_____	4.80	9_____	5.40	14_____	5.20	19_____	4.15
5_____	4.15	10_____	5.80	15_____	5.15		

Analyzes of coal samples from the San Juan County coal field, New Mexico, and other fields.

[Made at the Pittsburgh laboratory of the Bureau of Mines; A. C. Fleidner and F. M. Stanton, chemists in charge.]

Coal of the Menefee formation.

Mine and sampler.	Location.			Labors- dry No.	Air- dry- ing loss.	Form of anal- ysis.	Proximate.				Ultimate.					Heating value.	
	Quar- ter.	T. N.	R. W.				Mois- ture.	Vola- tile mat- ter.	Fixed car- bon.	Ash.	Sul- phur.	Hy- dro- gen.	Car- bon.	Nitro- gen.	Oxy- gen.	Calo- ries.	British ther- mal units.
Government mine; Max. A. Pichel, 1913.	SW.	21	16	17780	1.8	A B C D	10.6	38.7	49.6	3.1	0.64	.....	.....	.....	.....	6,115	11,010
							9.0	37.4	50.5	3.1	.65	.....	.....	.....	.....	6,235	11,210
							.....	41.1	55.4	3.5	.72	.....	.....	.....	.....	6,940	12,310
							.....	42.6	57.4	.....	.75	.....	.....	.....	.....	7,065	12,750
Government mine; Harvey Bes- ler, 1917.	SW.	21	16	28008	2.1	A B C D	10.1	29.9	45.8	4.2	.55	.....	.....	.....	.....	6,675	12,010
							8.2	40.8	46.8	4.2	.57	.....	.....	.....	.....	6,520	12,270
							.....	44.4	50.9	4.7	.95	.....	.....	.....	.....	7,425	13,370
							.....	45.6	53.4	.....	1.00	.....	.....	.....	.....	7,760	14,080
Tinsatin mine; M. E. Shaler, 1900.	(e)	(e)	(e)	28311	7.6	A B C D	15.8	35.0	39.8	9.1	1.78	5.53	55.74	1.39	25.79	5,540	9,970
							8.9	37.9	43.1	10.14	1.93	5.51	60.32	1.51	20.59	5,995	10,790
							.....	41.6	47.3	11.13	2.11	4.96	66.19	1.65	13.96	6,580	11,840
							.....	45.8	53.2	.....	2.38	5.59	74.48	1.86	15.99	7,400	13,320
Blake's mine; C. M. Benson, 1915A.	13	23	13	28008	11.2	A B C D	10.0	32.4	43.2	5.4	.92	.....	.....	.....	.....	5,665	10,190
							8.8	38.5	48.6	6.1	1.04	.....	.....	.....	.....	6,380	11,480
							.....	40.0	53.3	6.7	1.14	.....	.....	.....	.....	6,900	12,800
							.....	42.9	57.1	.....	1.23	.....	.....	.....	.....	7,496	13,490
Pueblo Bonito mine; C. M. Benson, 1915A.	14	21	11	28004	7.1	A B C D	14.4	34.8	43.3	7.5	1.54	.....	.....	.....	.....	5,660	10,220
							7.8	37.5	46.6	8.1	1.66	.....	.....	.....	.....	6,110	11,000
							.....	40.7	50.5	8.8	1.80	.....	.....	.....	.....	6,630	11,940
							.....	44.6	55.4	.....	1.97	.....	.....	.....	.....	7,270	13,090

Not shown

Navajo Indian Reservation.

Analyses of coal samples from the San Juan County coal field, New Mexico, and other fields—Continued.

Coal of the Fruitland formation.

Mine and sampler.	Location.			No. on Plate.	Laboratory No.	Air-drying loss.	Form of analysis.	Proximate.			Ultimate.					Heating value.					
	Quarter.	Section.	T. N.					R. W.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calorific res.	British thermal units.		
New Mexico mine; Max. A. Pichel, 1913.	.....	7	32	12	3	17749	1.6	A	6.6	35.4	44.9	13.1	0.66	.....	.....	.....	.....	6,390	11,490		
								B	5.1	36.0	45.6	13.3	.67	.....	.....	.....	.....	.....	.....	6,485	11,600
								C	.....	37.9	48.0	14.1	.71	.....	.....	.....	.....	.....	.....	6,833	12,300
								D	.....	44.1	55.9	.....	.83	.....	.....	.....	.....	.....	.....	7,950	14,310
Bill Thomas mine; Harvey Bassler, 1917.	NW.	22	32	13	9	29249	2.9	A	5.9	39.1	44.0	11.0	.63	.....	.....	.....	.....	6,995	12,050		
								B	3.2	40.2	45.3	11.3	.65	.....	.....	.....	.....	.....	.....	6,890	12,410
								C	.....	41.5	46.8	11.7	.67	.....	.....	.....	.....	.....	.....	7,120	12,810
								D	.....	47.0	53.0	.....	.76	.....	.....	.....	.....	.....	.....	8,090	14,510
Jones mine; Harvey Bassler, 1917.	SE.	21	32	13	10	29250	3.3	A	7.9	38.1	43.1	11.9	1.32	.....	.....	.....	.....	6,460	11,630		
								B	3.7	39.4	44.6	12.3	1.37	.....	.....	.....	.....	.....	.....	6,685	12,030
								C	.....	41.0	46.2	12.8	1.42	.....	.....	.....	.....	.....	.....	6,940	12,500
								D	.....	47.0	53.0	.....	1.63	.....	.....	.....	.....	.....	.....	7,960	14,330
Prospect drift; J. B. Reeside, Jr., 1917.	NW.	16	30	15	58	29026	1.4	A	9.6	37.2	40.5	12.7	2.36	.....	.....	.....	.....	5,850	10,530		
								B	8.3	37.7	41.1	12.9	2.39	.....	.....	.....	.....	.....	.....	5,935	10,900
								C	.....	41.2	44.8	14.0	2.61	.....	.....	.....	.....	.....	.....	6,475	11,900
								D	.....	47.9	52.1	.....	3.04	.....	.....	.....	.....	.....	.....	7,530	13,590
Marcellus mine; J. B. Reeside, Jr., 1917.	SW.	28	30	15	61	29025	1.4	A	8.8	41.7	41.2	8.3	.62	.....	.....	.....	.....	6,475	11,900		
								B	7.4	42.3	41.9	8.4	.63	.....	.....	.....	.....	.....	.....	6,570	11,520
								C	.....	45.7	45.2	9.1	.68	.....	.....	.....	.....	.....	.....	7,095	12,770
								D	.....	50.3	49.7	.....	.75	.....	.....	.....	.....	.....	.....	7,810	14,060
Black Diamond mine; Schrader and Shaler, 1906.	SW.	4	29	15	67	2494	4.5	A	9.9	38.4	41.5	10.2	.64	.....	.....	.....	.....	6,275	11,300		
								B	5.6	40.3	43.4	10.7	.67	.....	.....	.....	.....	.....	.....	6,570	11,500
								C	.....	42.7	46.0	11.3	.71	.....	.....	.....	.....	.....	.....	6,965	12,640
								D	.....	48.1	51.9	.....	.80	.....	.....	.....	.....	.....	.....	7,865	14,140
Black Diamond mine; C. M. Bauer, 1916.	SW.	4	29	15	67	22608	6.2	A	11.6	38.6	39.9	9.9	.60	.....	.....	.....	.....	6,107	10,790		
								B	6.7	41.1	42.9	10.6	.62	.....	.....	.....	.....	.....	.....	6,510	11,430
								C	.....	43.6	46.2	11.2	.68	.....	.....	.....	.....	.....	.....	6,905	12,630
								D	.....	49.2	50.8	.....	.77	.....	.....	.....	.....	.....	.....	7,775	13,000

L. W. Henderson mine; C. M. Bauer, 1916.	SW.	3	29	15	60	22609	5.1	A				10.5	38.6	41.7	9.2	60	11,210
								B	C	D							
Local pit; C. M. Bauer, 1915.....	(e)	(e)	(e)	(e)	301	22685	6.1	40.6	43.1	46.8	10.3	5.7	40.6	43.1	46.8	6.80	11,810
								43.1	46.8	50.3	10.3	5.7	43.1	46.8	50.3	6.80	12,330
								46.8	50.3	53.8	10.3	5.7	46.8	50.3	53.8	7.760	13,970
								50.3	53.8	57.3	10.3	5.7	50.3	53.8	57.3	8.805	10,640
Do.....	(e)	(e)	(e)	(e)	419	22807	5.8	16.1	38.6	40.7	7.0	16.1	38.6	40.7	7.0	5,805	10,640
								10.6	38.6	43.4	7.5	10.6	38.6	43.4	7.5	6,205	11,260
								43.4	43.1	46.5	8.4	43.4	43.1	46.5	8.4	6,980	12,560
								46.5	47.1	52.9	8.4	46.5	47.1	52.9	8.4	7,615	13,710
Do.....	(e)	(e)	(e)	(e)	419	22807	5.8	33.0	33.0	41.7	6.2	19.1	33.0	41.7	6.2	5,900	10,180
								14.1	36.0	44.3	6.6	14.1	36.0	44.3	6.6	6,010	10,810
								40.7	40.7	51.5	7.7	40.7	40.7	51.5	7.7	6,905	12,000
								51.5	44.1	55.9	7.7	51.5	44.1	55.9	7.7	7,580	13,540

a Navajo Indian Reservation.

Possibly competing coals in Colorado.

Durango, La Plata County.....	14772	2.0	A				3.0	34.8	55.3	6.01	0.74	5.50	76.36	1.50	8.99	7,690	13,710
			B	C	D												
Hesperus, La Plata County.....	14775	3.8	40.6	43.1	46.8	10.3	1.0	33.9	57.0	7.12	7.76	5.35	77.93	1.53	7.35	7,715	12,940
			43.1	46.8	50.3	10.3	1.0	36.0	61.3	7.12	7.76	5.35	78.75	1.53	7.35	7,865	14,140
			50.3	53.8	57.3	10.3	1.0	41.0	62.7	7.12	7.76	5.35	81.57	1.53	7.35	7,875	13,440
			57.3	58.2	59.1	10.3	1.0	43.8	66.2	7.12	7.76	5.35	81.57	1.53	7.35	8,068	14,550
Crested Butte, Gunnison County.....	7983	1.4	33.6	36.1	38.6	6.2	2.4	30.6	50.7	6.08	6.0	5.68	70.85	1.47	15.55	7,040	12,670
			36.1	38.6	41.1	6.2	2.4	33.6	53.2	6.08	6.0	5.68	73.65	1.47	15.55	7,320	13,170
			41.1	43.6	46.1	6.2	2.4	36.1	55.7	6.08	6.0	5.68	76.25	1.47	15.55	7,575	13,670
			46.1	48.6	51.1	6.2	2.4	38.6	58.2	6.08	6.0	5.68	78.75	1.47	15.55	7,875	14,170
Somerset, Gunnison County.....	12324	1.7	33.6	36.1	38.6	6.2	3.0	33.6	55.2	7.34	39	5.30	74.45	1.53	11.00	7,460	13,430
			36.1	38.6	41.1	6.2	3.0	36.1	57.7	7.34	40	5.30	76.25	1.53	11.00	7,565	13,830
			41.1	43.6	46.1	6.2	3.0	38.6	59.2	7.34	40	5.30	78.75	1.53	11.00	7,680	14,240
			46.1	48.6	51.1	6.2	3.0	41.1	61.7	7.34	40	5.30	81.57	1.53	11.00	7,800	14,640
Newcastle, Garfield County.....	12327	3.6	37.6	40.1	42.6	6.2	5.6	37.6	47.6	9.22	43	5.31	69.68	1.40	13.96	8,910	12,430
			40.1	42.6	45.1	6.2	5.6	40.1	49.1	9.22	44	5.31	70.85	1.40	13.96	9,010	12,830
			42.6	45.1	47.6	6.2	5.6	42.6	51.6	9.22	44	5.31	73.65	1.40	13.96	9,110	13,230
			45.1	47.6	50.1	6.2	5.6	45.1	54.1	9.22	44	5.31	76.25	1.40	13.96	9,210	13,630
Sunlight, Garfield County.....	4034	3.0	36.1	38.6	41.1	6.2	5.3	36.1	46.1	8.79	76	5.26	67.76	1.53	15.85	6,900	12,430
			38.6	41.1	43.6	6.2	5.3	38.6	48.6	8.79	76	5.26	69.68	1.53	15.85	7,000	12,830
			41.1	43.6	46.1	6.2	5.3	41.1	51.1	8.79	76	5.26	71.57	1.53	15.85	7,100	13,230
			43.6	46.1	48.6	6.2	5.3	43.6	53.6	8.79	76	5.26	73.65	1.53	15.85	7,200	13,630

Analyses of coal samples from the San Juan County coal field, New Mexico, and other fields—Continued.

Possibly competing coals in Colorado—Continued.

Mine and sampler.	Location.			Laboratory No.	Air-drying loss.	Form of analysis.	Proximate.			Ultimate.						Heating value.
	Quarter.	Section.	T. N. R. W.				Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulfur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	
Trinidad, Las Animas County.....				14060	0.6	A	1.5	30.8	54.4	13.32	0.53	4.98	73.10	1.71	0.36	7,230
						B	0.9	31.0	54.7	13.40	.53	4.94	73.54	1.74	5.37	7,265
						C	.....	31.3	55.2	13.53	.54	4.88	74.23	1.74	5.08	7,335
						D	.....	38.2	63.8	.....	.62	5.64	85.85	2.01	5.88	8,490
Cannon City, Fremont County.....				15395	5.8	A	10.3	38.2	45.0	6.49	.42	5.38	65.45	1.08	21.18	6,340
						B	4.7	40.6	47.8	6.89	.45	5.03	69.48	1.15	17.00	6,780
						C	.....	42.6	50.2	7.28	.47	4.74	73.94	1.20	12.42	7,070
						D	.....	46.0	54.0	.....	.51	5.11	78.62	1.29	14.47	7,620
Lafayette, Boulder County.....				15165	10.3	A	20.7	31.8	44.0	3.49	.45	6.04	87.80	1.20	31.02	5,525
						B	11.6	35.5	49.0	3.89	.50	5.46	84.44	1.34	24.37	6,150
						C	.....	40.1	55.5	4.40	.57	4.72	72.90	1.51	15.90	6,965
						D	.....	42.0	58.0	.....	.60	4.94	76.25	1.58	16.63	7,285

Possibly competing coals in New Mexico.

Gallup, McKinley County.....				19135	5.7	A	12.2	39.1	40.5	7.21	0.45	6.94	62.73	1.13	22.44	6,165
						B	7.9	41.5	42.9	7.56	.53	6.54	61.51	1.20	16.42	6,585
						C	.....	45.1	46.1	8.31	.55	6.28	59.26	1.30	15.32	7,100
						D	.....	48.2	50.8	.....	.57	6.74	78.81	1.42	13.46	7,745
Koehler, Colfax County.....				12338	1.9	A	8.6	34.1	48.3	12.00	.70	5.28	66.76	1.31	10.98	7,015
						B	1.8	36.8	49.2	12.22	.71	5.14	71.11	1.34	9.47	7,150
						C	.....	37.5	50.1	12.43	.73	5.03	72.40	1.36	8.03	7,280
						D	.....	42.8	57.2	.....	.83	5.76	82.70	1.55	9.17	7,300

Possibly competing coals in Utah.

Thompson, Grand County.....	17577	2.0	A	7.1	37.1	43.4	10.44	0.67	5.59	65.96	1.45	15.38	6,510	11,720
			B	5.3	37.8	46.3	10.65	.67	5.48	67.29	1.48	14.43	6,640	11,960
			C	.....	39.9	48.9	11.24	.71	5.17	71.06	1.66	10.37	7,010	12,620
			D	.....	44.9	56.1	.....	.80	5.53	80.04	1.76	11.53	7,896	14,210
Bunnyside, Carbon County.....	12630	1.5	A	5.1	38.4	48.7	7.81	.51	5.54	70.72	1.58	13.84	7,010	12,620
			B	3.6	39.1	49.4	7.98	.53	5.45	71.80	1.60	12.70	7,120	12,810
			C	.....	40.5	51.3	8.23	.54	5.25	74.49	1.66	9.83	7,386	13,290
			D	.....	44.1	55.9	.....	.59	5.72	81.17	1.81	10.71	8,045	14,490
Castlegate, Carbon County.....	19880	1.0	A	3.3	42.5	48.0	6.19	.40	5.60	73.22	1.35	13.24	7,290	13,090
			B	2.3	43.0	48.5	6.25	.40	5.54	73.99	1.36	12.46	7,335	13,200
			C	.....	44.0	49.6	6.40	.41	5.41	75.72	1.40	10.66	7,606	13,510
			D	.....	47.0	53.0	.....	.44	5.78	80.90	1.50	11.38	8,020	14,430

The sections of the coal beds at the points sampled, except those shown below, are given in the plates of graphic sections, and the parts included in the sample are marked by an asterisk.

Section of coal beds in Tiznatzin mine, on Coal Creek 2 miles above mouth, in T. 23 N., R. 14 W., unsurveyed.

[Analysis 3811.]			
Sandstone.		Ft.	in.
Coal		1	8
Bone.....✓			5
Coal *.....		3	2
Shale.			
		5	3

Section of coal beds in Pueblo Bonito mine, 1 mile southwest of Putnam (Pueblo Bonito), in T. 21 N., R. 11 W.

[Analysis 23004.]			
Sandstone.		Ft.	in.
Bone.....			2
Coal *.....		2	8
Bone, sandy			6
Coal *.....		1	7
Shale, carbonaceous.....		2	6
Coal, impure.....		2	4
Shale.			
		9	9

Section of coal beds in Blake's mine, sec. 13, T. 22 N., R. 13 W.

[Analysis 23003.]			
Sandstone.		Ft.	in.
Coal *.....		1	7
Shale, carbonaceous.....		1	1
Coal.....		1	5
Sandstone.			
		4	1

ASH TESTS.

Tests were made in the field of the ash content of samples from a number of beds, and at the same time note was made of the air-drying loss. The tests were made with a small portable outfit, devised by C. E. Leshner.¹⁶ Samples collected at locations 140, 145, 154, 155, 230, 235, and 545 represented beds or benches of coal whose purity was uncertain and whose value the geologist wished to know in the field. The other samples were tested as representative of the coal at the outcrop. Each sample for the ash test was taken from a clean

¹⁶ Leshner, C. E., Field apparatus for determining ash in coal: U. S. Geol. Survey Bull. 621, pp. 1-12, 1915.

face of the bed by picking off, as nearly as possible, an even amount from all parts of the face so as to obtain a fair representation of the character of the bed.

The high ash content of samples from locations 153, 167, 224, and 231, as compared with that of samples from mines, would seem to indicate the presence of some foreign material in the weathered part of the coal bed, possibly mineral salts deposited by the evaporation of ground water.

Ash tests of coal from the Menefee formation.

Location 145.

Section.		Ash (per cent).	Moisture (per cent).
Shale.			
Coal.....	<i>Ft. in.</i> 2	22.2	11.1
Shale.			

Location 235.

Shale.			
Coal, bony.....	1 7	21.5	10.6
Bone.....	4		
Shale.	1 11		

Ash tests of coal from the Fruitland formation.

Location 140, Navajo mine, south side of San Juan River.

Section.		Ash (per cent).	Moisture (per cent).
Shale, carbonaceous.	<i>Ft. in.</i>		
Coal, bony.....	1 8	16.6	6.3
Shale, sandy.....	6		
Bone.....	5		
Coal.....	0	11.6	2.2
Shale.....	1 5		
Coal and bone.....	9		
Shale, carbonaceous.....	1		
Coal, impure.....	3 7	20.2	2.6
Shale, sandy.....	3		
Coal, impure.....	4		
Shale, sandy.....	1		
Bone.....	6		
Coal.....	1 4		
Shale, sandy.....	3		
Coal, impure.....	2 11	27.5	1.7
Bone.....	4		
Shale.....	1		
Bone.....	5		
Shale.	14 10½		

Location 154.

Shale, carbonaceous.			
Bone.....	2 5	33.2	10.4
Shale, carbonaceous.			

Ash tests of coal from the Fruitland formation—Continued.

Location 155.

Section.		Ash (per cent).	Moisture (per cent).
Shale, black, carbonaceous.	<i>Ft. in.</i>		
Bone.....	2		
Coal.....	3		
Bone.....	8		
Shale.....	1		
Coal, impure.....	2 9	27.0	11.3
Shale.....	3		
Coal.....	11		
Shale.....	1		
Bone.....	6	34.5	10.2
Coal.....	6		
Bone.....	2		
Coal.....	10		
Shale.....	7 0		

Location 230.

Shale, carbonaceous.			
Coal.....	1 8		
Bone.....	1		
Sandstone.....	2 3	28.5	8.8
Coal, bony; contains wheelerite.....	2 3		
Shale.....	4 3		

Location 545.

Sandstone.			
Coal, impure.....	7		
Shale.....	3		
Bone.....	1 10		
Sandstone.....	5		
Coal, bony.....	1 2	28.5	7.4
Shale.....	1 4		
Coal, bony.....	2 10	31.0	8.7
Shale.....	8 5		

Location 153.

Shale, carbonaceous.			
Coal.....	1 2	16.2	12.4
Shale.....			

Location 167.

Shale.			
Bone.....	7		
Coal, impure.....	3 8	17.3	6.3
Bone.....	1		
Sandstone.....	1		
Bone.....	1		
Coal.....	3		
Bone and shale.....	3		
Coal.....	2 2		
Shale.....	1		
Coal.....	1 0		
Bone.....	2		
Shale.....	8 5		

*Ash tests of coal from the Fruitland formation—Continued.***Location 224.**

Section.		Ash (per cent).	Moisture (per cent).
Shale, carbonaceous.	<i>Ft. in.</i>		
Coal, impure	2 7	21.5	5.5
Shale, carbonaceous	1 5		
Bone	5		
Shale.	4 5		

Location 231.

Shale, carbonaceous.			
Bone	3	17.7	3.8
Coal, impure	3		
Sandstone	1		
Coal, impure	3 8		
Bone	2		
Coal	11		
Shale.	5 4		

QUANTITY OF COAL IN THE FRUITLAND FORMATION.

By assuming that the average conditions at the outcrop of a coal-bearing formation persist in depth it is possible to estimate the amount of coal present. The value of the estimate of course depends on the amount and character of the information available. Where good contour maps of the field exist and the position, dip, and thickness of the coal beds and overlying strata are known, fairly accurate estimates may be made. Where less detailed information is at hand, more assumptions are necessary, and the result is of course less exact. The method used depends on the character of the coal beds, their attitude with reference to the surface, and the topography of the field.

In estimating the amount of coal in the Fruitland formation of San Juan County only the area under which the coal is not deeper than 1,000 feet was considered. This area was divided into a number of narrow strips running perpendicular to the outcrop, the total thickness of coal at the outcrop and the area were obtained for each strip, and on the assumption that an acre-foot contains 1,800 tons of coal the tonnage was calculated for each strip. The sum of these amounts gives the coal beneath 1,000 feet or less of cover as 16,288,000,000 tons and the total area underlain as 747 square miles.

It must be remembered, however, that these figures represent the total amount of coal and not necessarily the amount that may be mined. The recoverable amount is variable, depending upon mining practice and the care exercised in extracting the coal. As it is probable that the percentage of recovery will constantly tend to get

nearer and nearer 100, it is not thought wise to make an estimate on that basis.

Another estimate was made by taking an average of the total thickness of coal exposed at a number of places on the outcrop, the figure for each place being weighted by multiplying it by the sum of half the distances to the two adjacent places. The average thickness thus obtained (21 feet) was then multiplied by the total area underlain by the coal beds and the product reduced to tons. The resulting figure was 18,069,000,000 tons. This method does not take into account the relatively small size of the area underlain, within the depth limit, by the thick coal beds of the northern part of the field, and the estimate is therefore larger than that obtained by the first method.

The figures given above include all the coal beds observed. As some beds undoubtedly are not exposed and escaped observation, the estimate is not unwarrantedly high for the total coal content. Perhaps one-third of the coal represented in the estimates is in beds less than 14 inches thick and is therefore of small value under present economic conditions. Furthermore, no account was taken of partings, which in some parts of the field considerably reduce the value of the thicker beds. Locally the partings make up a third or more of the total thickness, but on the average they are very much less than that amount. If a tenth is allowed, however, for these partings the amount of usable coal at a depth of less than 1,000 feet is still nearly 10,000,000,000 tons.

Sufficient data are not yet available concerning the area in which the coal lies deeper than 1,000 feet to estimate the quantity, but it is probable that between the depths of 1,000 and 2,000 feet at least as much coal is present as there is at a depth of less than 1,000 feet.

COAL IN THE MENELEE FORMATION OF THE MESAVARDE GROUP.

The Mesaverde group was examined in detail only in T. 30 N., R. 16 W., and small adjoining tracts to the east and south. Its upper boundary is elsewhere the limit of the field studied. However, sections of coal beds were measured at several places south of San Juan River, samples of the coal were obtained for analysis (see table, p. 183), and where Chaco River cuts through the Great Hogback a section through the entire group was examined. These data are considered below.

COAL IN T. 30 N., R. 16 W., AND ADJACENT TRACTS.

The coal beds of the Menefee formation in T. 30 N., R. 16 W. (Pl. XXIII), are in two groups, one near the top and the other near the base. This grouping is well shown in the section on San Juan River. (See p. 163.) Individual beds in both groups are lenticular, though

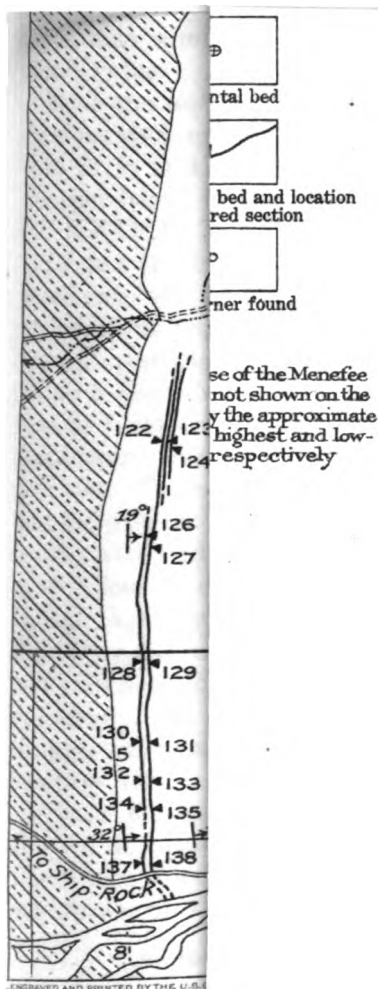
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some may be traced for several miles along the outcrop, and one was followed for nearly 6 miles. Some beds show in places a considerable thickness of clear coal, the maximum observed being 11 feet 6 inches, though as a whole partings are numerous and the value of the beds is thereby lessened.

The only mine in the township is that at location 104 (see Pl. XXIII), which supplies the Indian school and agency at Ship Rock. Production is limited to the needs of this institution. The coal bed mined here is 6 feet 2 inches thick and without partings.

The lower group of coal beds includes at most points two major beds, also some short lenses and locally a number of thin beds of small value.

Near the north side of T. 30 N., R. 16 W., and in R. 15 W. two sections were measured on a short but valuable lens of coal. At location 71 it is 3 feet 6 inches thick with a streak of coal above and another below it, and at location 72 it is 7 feet 8 inches thick. (See Pl. XXIV.) The bed thins out north and south of these locations.

In sec. 10 two beds crop out which may be traced southwestward into sec. 29. The lower of these beds is represented by sections at locations 88, 90, 94, 102, and 105. (See Pl. XXIV.) It has numerous partings and is not of high value. A short lens of small value 5 feet above the last-mentioned bed is represented by the section at location 106. The higher of the two beds, 20 to 25 feet above the lower, was examined at locations 89, 91, 95, 103, 104, 107, 108, and 109. The sections are shown on Plate XXIV. At location 89 this bed is split by 5 feet of shale into two thin beds, but the shale thins southward and disappears; and at locations 95, 103, and 104 there is over 6 feet of clear coal. Location 104 is the mine of the Ship Rock Indian Agency, from which two samples have been taken for analysis. (See table, p. 183.) Farther south, at locations 108 and 109, the bed pinches down to about 2 feet of coal and is overlain by a thin, valueless lens. Neither of these beds can be traced farther south, though they may be connected with those shown in the section at location 122.

Above the higher bed represented by the sections at locations 91 and 95 a number of thin beds of small lateral extent are present. These are described in the following stratigraphic sections but are not shown on the map:

Section of strata above the higher bed at location 91.

	Ft.	in.
Sandstone-----	15	
Shale, carbonaceous-----	10	
Coal-----		4
Shale, carbonaceous-----	3	6
Coal-----	3	6

	Ft.	in.
Shale, carbonaceous-----	14	
Coal-----	3	8
Shale, carbonaceous-----	4	
Coal-----		5
Bone-----		6
Coal-----		4
Shale, carbonaceous-----	1	6
Coal-----	1	8
Shale, carbonaceous-----	10	
Sandstone-----	8	
Shale, carbonaceous-----	6	
Coal bed of section 91, Plate XXIV.		
Total section-----	82	5
Total coal-----	9	11

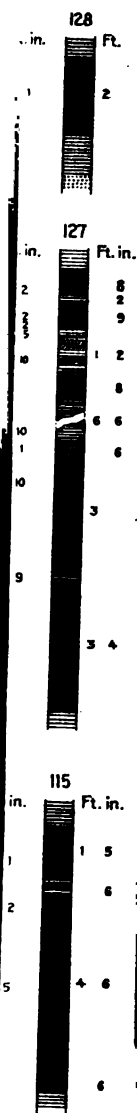
Section of strata above the higher bed at location 95.

	Ft.	in.
Sandstone and shale, yellow-----	15	
Shale, carbonaceous-----	4	
Coal-----		6
Shale, carbonaceous-----	1	
Coal-----	1	1
Shale and sandstone-----	10	
Coal-----	1	
Shale and sandstone-----	30	
Coal-----	1	3
Shale and sandstone-----	15	
Coal-----		6
Shale and sandstone-----	10	
Coal bed of section 95, Plate XXIV.		
Total section-----	89	4
Total coal-----	4	4

A coal bed crops out in sec. 29 which may be traced southward to San Juan River. It is shown in sections at locations 122, 127, 129, 131, 133, 135, and 138. (See Pl. XXIV). It is variable in thickness and purity, though locally, as at location 138, it reaches 5 feet in thickness and has few partings. At locations 122, 127, 131, and 138 it is overlain at a distance ranging from 4 to 6 feet by a thin bed of small value.

Beneath the bed represented by sections 122 and 138, and separated from it by 5 to 10 feet of shale, is a thin bed of coal which was examined at locations 128, 130, 132, 134, and 139. It is less than 2 feet thick in most of the sections. (See Pl. XXIV.)

In sec. 29 the coal bed of section 122 is overlain by two lenses. The main bed at location 123 is separated by 12 feet of shale and sandstone from the first bed above, which is 8 feet thick. (See Pl. XXIV). At 30 feet higher is the second lens, which is shown in the section at location 124 and is 3 feet thick at that point. These lenses can be traced laterally only a short distance.



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Above the higher bed of section 138 at the same locality several thin lenses are present, which are shown in the following section:

Section of strata above the higher bed at location 138.

Shale.	Ft.	in.
Coal	1	2
Shale and sandstone.....	246	
Coal.....		4
Shale, carbonaceous.....	1	2
Coal.....	1	
Shale and sandstone.....	10	
Coal.....	1	1
Shale.....	28	
Sandstone.....	12	
Shale.....	1	
Coal.....	1	
Shale.....	20	
Coal bed of section 138, Plate XXIV.		
Total section.....	320	9
Total coal.....	4	7

The upper group of coal beds contains one rather persistent bed overlain and underlain by lenses of varying extent. In sec. 32, T. 30 N., and sec. 4, T. 29 N., practically no workable coal was observed in the upper part of the Menefee formation, though the exposures are very good.

The persistent coal bed of the upper group is represented on Plate XXIV by sections made at locations 74, 76, 79, 81, 83, 84, 86, 92, 96, 98, 100, 110-A, 110-B, 110-D, 111, 112, 113, 115, 116, 118, 120, and 121. It is the thickest and most valuable coal bed of the township. At location 74 it is either absent or represented by a layer of coal 6 inches thick. At location 76 it is 1 foot 1 inch thick; at location 79, 2 feet 10 inches; at location 81, 5 feet; at location 83 it thins to 2 feet. From this point it increases toward location 98, where it is 11 feet 6 inches thick and free from partings. Southward from location 98 it decreases in thickness and value, and at location 121 it is 3 feet 3 inches thick. Beyond this point it vanishes.

In sec. 5, T. 30 N., R. 15 W., the persistent bed is underlain by a lens which at location 73 is 4 feet thick, its maximum. (See Pl. XXIV.) The intervening strata are 28 feet thick.

In sec. 6, T. 30 N., R. 15 W., the persistent bed is underlain by two lenticular beds, which were mapped, and several minor lenses. The lower bed, measured at location 77 (see Pl. XXIV), is of small extent and 3 feet thick at its maximum. Ten feet above it lies the second lens, examined at locations 75, 78, 80, and 82. This bed increases from 2 feet 2 inches in thickness at location 75 to 4 feet 8 inches at location 80 and decreases to 1 foot at location 82. At location 75, between the bed shown in section 77 and that in section

75, a lens about 200 feet long is 12 feet thick at the middle but thins out within 100 feet on each side of the point of maximum thickness, and there is also a thin bed not shown on the map. At location 80 a thin bed of small extent likewise underlies the bed shown in section 80. The sections of these lenses are given graphically on Plate XXIV. The upper lens mapped is from 20 to 30 feet beneath the persistent bed.

In sec. 14, T. 30 N., R. 16 W., the persistent bed is underlain by a short lens examined at location 85. It is 2 feet 6 inches thick at its maximum and lies 10 feet beneath the persistent bed.

In sec. 28 a short lens was mapped which is shown by the section at location 114. (See Pl. XXIV.)

Above the persistent bed two lenses were mapped. One is shown by the sections at locations 87, 93, 97, 99, 101, and 110-C. It reaches a maximum thickness of 9 feet at location 99 and thins in either direction from that point. It lies from 15 to 20 feet above the persistent bed. The second lens was examined at locations 117 and 119. It is a little over 3 feet in thickness at both points and is separated from the persistent bed by 20 to 30 feet of shale and sandstone.

At location 125 a section (see Pl. XXIV) was measured which contains a coal bed 4 feet thick, and in addition three beds too thin to be of value. None of them can be traced very far laterally.

At locations 136 and 137 occurs a lens which increases from 3 feet 7 inches to 7 feet 6 inches in thickness within a very short distance. It can not be traced southward because of alluvial cover, but, to judge by other very variable beds, it is probably not extensive. Twenty feet below this bed at location 137 the following section was measured:

Section of lenticular coal bed at location 137.

Shale, carbonaceous, sandy.	Ft.	in.
Bone-----	6	0
Shale, carbonaceous-----	2	6
Coal-----	1	0
Shale, carbonaceous-----	1	0
Coal-----	1	2
Shale, carbonaceous-----	4	
Coal-----		4
Shale, carbonaceous, sandy.		
Total section-----	16	0
Total coal-----	2	6

COAL SOUTH OF SAN JUAN RIVER.

A section of the Mesaverde group where Chaco River cuts through the Great Hogback is given on page 165. This section exhibits very little coal. Only three thin beds are exposed, at locations 145, 146,

and 147, in the zone covered by the lower group of beds. It seems possible that, owing to the abrupt folding of the strata, any coal beds present in the upper part of the Menefee formation have been squeezed out, though it is true that at some places north of the San Juan no coal can be found even where exposures are unusually good. The lowest coal bed at location 145 shows 2 feet of coal (moisture 11 per cent, ash 22 per cent). At location 146 there is 8 inches of coal, and at location 147 the coal bed is 10 inches thick. At all three of these locations the coal is overlain and underlain by shale.

Sections of coal beds and inclosing strata of the Menefee formation at other places are given below. They all fall within the zone of the upper group of beds.

Section of coal beds at location 179, 1½ miles southeast of mouth of Ojo Amarillo Arroyo.

	Ft.	in.
Sandstone, nearly white, easily weathered.....	45	
Sandstone, buff, fine grained.....	18	
Shale, light gray and yellow, sandy.....	18	
Sandstone, buff, massive.....	56	
Shale.....		2
Coal.....	3	5
Shale, brown, carbonaceous.....	2	2
Coal.....	3	4
Shale, blue-gray, with thin streaks of coal.....	26	
Coal.....	3	5
Shale, blue-gray, with streaks of coal.....	18	6
Coal.....	3	7
Shale.....	12	
Sandstone, massive.....		
Total section.....	209	7
Total coal.....	13	9

Section of coal beds at location 235, 5 miles west of mouth of Cottonwood Arroyo.

	Ft.	in.
Sandstone, massive, light yellow, weathering pink.....	65	
Shale, gray, carbonaceous.....	15	
Shale, gray.....	12	
Coal.....	1	7
Bone.....		4
Shale, carbonaceous.....	2	3
Coal, weathered.....	3	8
Shale, carbonaceous.....	8	
Sandstone.....	4	
Shale.....	6	
Coal.....	2	8
Shale, gray.....	16	
Sandstone, hard, platy.....	4	6
Shale, carbonaceous.....	3	

	Ft.	in.
Sandstone, forming cliff.....	22	
Shale, carbonaceous.....	3	
Coal.....	1	
Shale, carbonaceous.....	2	
Sandstone, pink.....	14	
Shale, gray, sandy.....	10	
Shale, dark gray, containing several 3-inch beds of coal....	5	6
Shale, black, carbonaceous.....	4	6
Coal.....		10
Shale, dark gray.....	61	
Coal.....		3
Shale, carbonaceous.....	2	
Coal.....		5
Shale, dark gray.....	18	
Coal.....		10
Shale.....	12	
Sandstone.....	15	
Shale, gray, with carbonaceous streaks.....	21	
Coal.....	1	5
Shale, carbonaceous.....	3	
Sandstone.....	3	
Shale, carbonaceous.....	4	
Coal.....	1	2
Shale, carbonaceous.....	35	
Sandstone.....	5	
Shale, dark, carbonaceous.....	87	
Shale and sandstone in alternating thin beds.....	195+	
Total section.....	661+	
Total coal.....	13	10

Section of coal bed at Tiznatzin mine, on Coal Creek 2 miles above mouth.

[Highest coal bed of Mesaverde group.]

	Ft.	in.
Sandstone.		
Coal.....	1	8
Bone.....		5
Coal, sampled.....	3	2
Shale.		
	5	3

(See analysis 3811, p. 183.)

Section of coal bed at location 548, at Blake's store.

	Ft.	in.
Sandstone.		
Coal, sampled.....	1	7
Shale, carbonaceous.....	1	1
Coal, sampled.....	1	5
Sandstone.		
	4	1

(See analysis 29008, p. 183.)

Section of strata at location 549, on Meyers Creek 1 mile above mouth.

	Ft.	in.
Cliff House sandstone.....	369	
Menefee formation:		
Shale, brown, carbonaceous.....	14	
Coal, impure.....	1	6
Shale, brown, carbonaceous.....	40	
Sandstone, brown.....	15	
Shale, carbonaceous.....	12+	
	451+	

Section of coal bed at Pueblo Bonito mine, 1 mile west of store at Pueblo Bonito.

[Highest coal bed of Mesaverde group.]

	Ft.	in.
Sandstone.		
Bone.....		2
Coal, sampled.....	2	8
Bone, sandy.....		6
Coal, sampled.....	1	7
Shale, carbonaceous.....	2	6
Coal, impure.....	2	4
Shale.		
	9	9

(See analysis 23004, p. 183.)

Another section of the bed represented by the last section, taken at a different point in the same mine, shows the following:

Section of coal bed at Pueblo Bonito mine.

	Ft.	in.
Sandstone.		
Bone.....	1	6
Coal, sampled.....	3	8
Bone.....		4
Coal, sampled.....	2	4
Shale.		
	7	10

COAL IN THE FRUITLAND FORMATION.**GENERAL FEATURES.**

In the following description of the coal of the Fruitland formation the field will be treated arbitrarily as a number of districts suggested by the surface features or by the continuity of exposures of the beds themselves. These districts are not distinct divisions, and their boundaries are therefore in large part indefinable. They are selected simply for convenience in presenting details that could not be set forth so readily if the field were treated as a whole.

Certain general features of interest, however, may be noted concerning the coals of the Fruitland formation. The outcrop, as shown

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on Plate XVI, is confined to a narrow belt running from the boundary between Colorado and New Mexico at first southwestward, then westward, then southward to San Juan River. From the San Juan it runs parallel to Chaco River as far as the south boundary of San Juan County. The beds dip southeastward in the northern part of the field, eastward in the central part, and northeastward in the southern part to relatively slight depths beneath the overlying rocks. This surface distribution and attitude are, of course, to be expected, inasmuch as the field is part of a great structural basin. (See p. 161.) The Fruitland formation continues beyond the limits of this field and completes a great circuit, of which the part here described forms nearly the western half. The exposures are best in the arroyos. The thickest and most valuable beds of coal are in the northern part of the field, though there is considerable coal in the middle part. In the southern part the beds are thin and very lenticular and the coal is poor. (See Pl. XXII.)

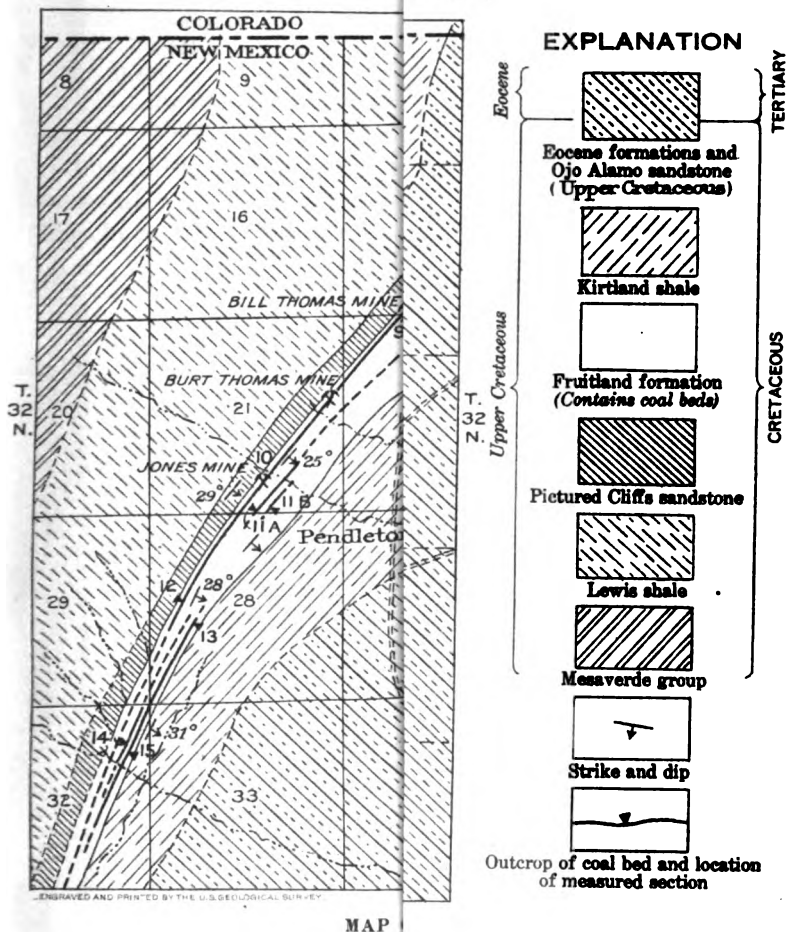
LA PLATA VALLEY.

The coal in the La Plata Valley district, which extends from location 1 to location 15 (see Pl. XXV), occurs in two main beds with a number of minor lenses. At location 1 a lens of coal 2 feet thick rests directly upon the Pictured Cliffs sandstone. It was not noted elsewhere in the district. From 6 to 30 feet above this horizon lies the bed which was examined at locations 1, 3, 4, 9, 10, and 12. It is from 23 to 38 feet in total thickness, being thus the largest observed in the whole field, and has been correlated with the Carbonero¹⁷ bed, formerly mined at Carbon Junction, near Durango, Colo. Whether this correlation is valid or not, the bed is certainly thick and valuable in the district just north of the State boundary line. Its character is shown in the sections on Plate XXVI. Parts of it are being mined at five places in this district, from three of which samples have been obtained for analysis. (See p. 184.) The product from the bed is used entirely for local consumption.

From 100 to 125 feet above the Carbonero bed lies another bed which was measured at location 2. It is extensively developed to the north, in Colorado. In this district it is much split by partings and can not be traced very far. The section is given graphically on Plate XXVI.

Farther south a lenticular bed about 180 feet above the Carbonero bed can be traced for some distance, but it is of small value except at location 5 because of partings. The section is given on Plate XXVI. At location 11-A it shows the following section:

¹⁷ Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico; U. S. Geol. Survey Bull. 316, pp. 392-398, 1906.



Section of coal bed at location 11-A.

Shale.	Ft.	in.
Coal		2
Shale, carbonaceous		4
Coal	1	5
Shale, carbonaceous		6
Coal		3
Shale, carbonaceous		1
Coal		5
Shale		1
Coal		1
Shale.		
Total section	3	4
Total coal	2	4

Beneath the bed examined at location 5 there are several unmapped lenses of coal whose value is small because of thinness or partings. The character of these beds is indicated in the following section:

Section of coal beds beneath that examined at location 5.

	Ft.	in.
Sandstone	10	
Shale	2	
Coal bed of location 5 (see Pl. XXVI)	5	7
Shale	40	
Sandstone	2	
Shale	40	
Coal and bone	1	6
Shale	2	6
Coal	1	3
Shale	5	
Coal	1	
Shale		9
Coal		9
Shale		1
Coal		3
Shale		1
Coal		2
Shale		1
Bone		1
Shale		6
Coal		4
Bone		3
Coal		5
Shale		9
Bone		2
Coal		3
Shale	15	
Coal	2	
Shale	5	
Total section	137	8½
Total coal	12	8

At location 11-B a thick coal bed is exposed, but it is of short lateral extent and much cut up by partings. The section is shown on Plate XXVI.

Between the coal bed of location 11-A and that of location 11-B several lenses are present, which are shown in the following section:

Section of coal beds between locations 11-A and 11-B.

Shale.		
Coal bed of location 11-B (see Pl. XXVI).	Ft.	in.
Shale, carbonaceous.....	4	
Sandstone.....		10
Shale, carbonaceous.....	40	
Coal.....		10
Shale.....		9
Coal.....	1	9
Coal, impure.....	1	
Shale, carbonaceous.....	4	
Coal.....		9
Bone and shale.....		8
Coal.....		5
Shale.....		4
Bone and bony coal.....		8
Shale.....		3
Bone.....		6
Shale, carbonaceous.....	37	
Sandstone.....	5	
Shale.....	5	
Coal bed of location 11-A (see p. 201).		
Total section.....	103	9
Total coal.....	4	9

At locality 6 two lenses are present close together at about the middle of the Fruitland formation. At locations 7 and 8 two lenses in the upper part of the Fruitland formation about 100 feet apart are shown. None of these lenses are extensive enough to be of great value. The sections are all shown on Plate XXVI.

A short lens is represented by the section obtained at location 14. (See Pl. XXVI.) At 12 feet above this lens is another one, unmapped. Its character is shown by the following section:

Section of coal lens between locations 14 and 15.

Shale, carbonaceous.	Ft.	in.
Bone.....		1
Shale.....		3
Coal.....		6
Shale.....		5
Coal.....		9
Shale.....	1	

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Ft.in.

31

3

Shale, carbonaceous—Continued.		Ft.	in.
Coal	-----	10	
Coal, bony	-----	2	
Coal	-----	7	
Shale.			
Total section	-----	4	7
Total coal	-----	2	10

At locations 13 and 15 a lens was examined which has but small value because of numerous partings. The sections are shown on Plate XXVI. It lies about 70 feet above the bed shown at location 14 and may be the same as the bed at location 11-B.

LA PLATA-SAN JUAN DIVIDE.

Along the La Plata-San Juan divide, from location 16 to location 37 (see Pl. XXVII), the lowest coal-bearing bed rests immediately upon the Pictured Cliffs sandstone. Higher up in the Fruitland formation there are three other fairly persistent beds and some minor lenses. Between locations 36 and 37 an abnormal development of sandstone occurs and little coal can be found, though the exposures are favorable.

The basal bed was examined at locations 21, 25, 28, 31, 34, and 37. It is variable in thickness and character, as the sections on Plate XXVI show. At location 37 the bed is only 1 foot thick.

The Carbonero bed in this district can not be directly connected with that in the district to the north, but the covered interval is short, and there is little doubt as to their identity. The bed was examined at locations 16, 19, 22, and 26. It lies from 30 to 50 feet above the Pictured Cliffs sandstone, and though some of the sections are incomplete it evidently decreases in thickness southward. For some miles southwest of location 26 no sections of it were obtained. Near location 37, in the zone where it ought to be found, only a little bone and dark shale are present, and it very probably thins out between locations 26 and 37.

From 100 to 120 feet above the Carbonero bed a higher bed was measured at locations 17, 20, 23, 29, 32, 35, and 36. It is of considerable thickness but much cut up by partings and consequently of small value.

From 75 to 100 feet above the last-mentioned bed occurs another bed which was measured at locations 24, 27, 30, and 33. It is thin and split by partings.

At location 18, 85 feet above the bed of location 17, a lens is present which may represent the horizon of the bed at location 24. It contains 4 feet 5 inches of coal with one thin parting. The section is shown on Plate XXVI.

DISTRICT ADJACENT TO YOUNGS RESERVOIR.

The district adjacent to Youngs Reservoir extends from location 39 to location 56. (See Pl. XXVII.) Between location 37 and location 39 a stretch of perhaps half a mile yields little evidence of coal beds. However, the basal coal bed is present in the district, coal is found at the horizon of the Carbonero bed, and a number of isolated lenses occur.

The basal coal was examined at locations 38, 40, and 43. It ranges in thickness from 4 feet 3 inches to 6 feet 2 inches with some partings. The sections are shown on Plate XXVI.

The Carbonero bed in this district is about 30 feet above the basal bed. It was measured at locations 39, 42, 44, 45, 47, and 56. At location 53 its presence is shown by "smut." Relatively the bed is thin, but it is the best in the district, as is shown by the sections (Pl. XXVI).

At location 41 and also at location 46 there is a short lens of coal about 85 feet above the base of the Fruitland formation. The first is thick and of some value; the second is much split by partings. At location 48 a section of a lens 17 feet above the Carbonero bed was measured. It is 7 feet thick with one parting. (See Pl. XXVI.)

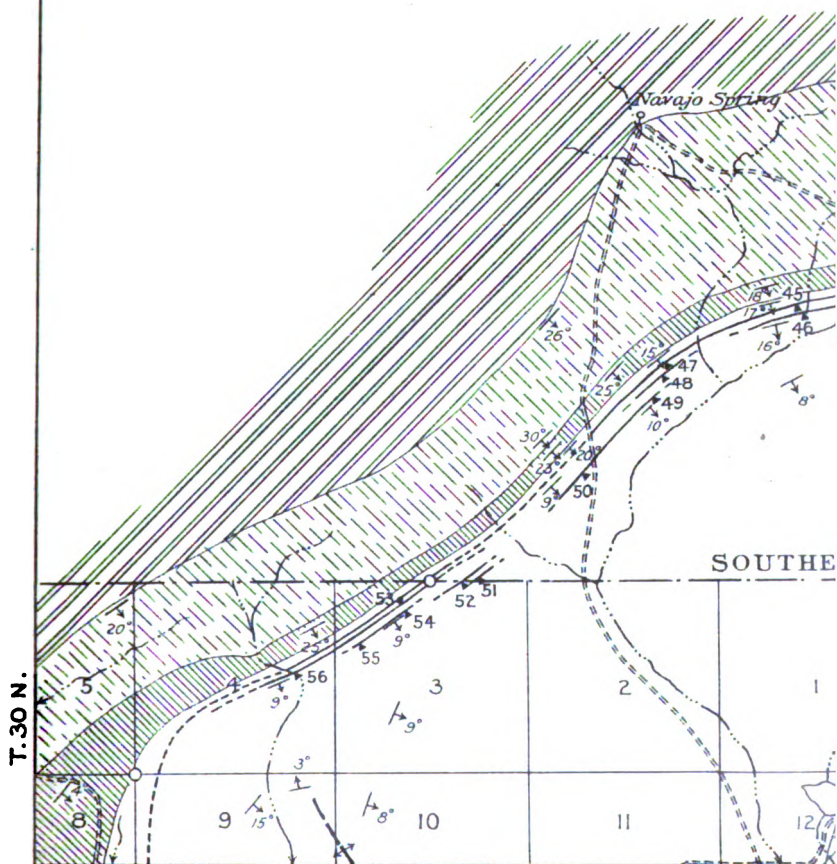
Sections were measured at locations 49 and 50 on a bed about 75 feet above the Carbonero bed. These sections are given on Plate XXVI. The bed is not of great value because of partings.

Sections at locations 51, 52, and 53 show small, thin lenses. The first is shown on Plate XXVI; the second has a little bone and 1 foot 1 inch of coal; the third, a little bone and 1 foot of coal.

Sections at locations 54 and 55 (Pl. XXVI) show the character of a short lens about 50 feet above the horizon of the Carbonero bed. It is of small value.

CENTRAL PART OF T. 30 N., R. 15 W.

The coal of the central part of T. 30 N., R. 15 W. (see Pl. XXVIII), is in two beds, the lower of which is at the horizon of the Carbonero bed, 20 to 30 feet above the base of the Fruitland formation. Sections were obtained of this bed at locations 57, 58, 61, and 65 and are shown on Plate XXVI. At location 59 a well sunk in prospecting for oil is reported to have passed through "15 feet of coal." At location 60 another well passed through "16 feet of coal." A prospect at location 58 shows the upper part of the bed and supplied a sample for analysis (No. 29026, p. 184). At locality 61 a mine known locally as the Marcellus mine, not now in operation, supplied a sample for analysis from the lower part of the bed (No. 29025, p. 184). A mine was opened some years ago at location 65, but the workings were not extensive, and it is now abandoned and badly caved in.



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R. 15 W.
MAP OF DISTRICT BETWEEN

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Another bed 50 feet above the Carbonero bed was examined at locations 62, 63, and 64. The sections are shown on Plate XXVI. It is of small value.

At location 58 a lens 2 feet 6 inches thick occurs 8 feet above the Carbonero bed. It could not be traced far laterally.

SAN JUAN RIVER.

The district near San Juan River (see Pl. XXVIII) produces a large share of the coal mined in the field, though the developments are not extensive and the product is all consumed locally. Two mines are in operation north of the river, both of which were sampled for analysis (Nos. 2464, 22508, and 22509, p. 184). An open pit on the south bank of the river opposite Fruitland furnishes the Navajo Indians with fuel. The two beds found in the district to the north are present here.

The lower bed was examined at locations 66, 67, 69, 140, and 144 (Pl. XXVI). At location 67, at the Black Diamond mine, northwest of Fruitland, the bed is over 15 feet thick and contains a number of partings. At location 69, at the Hendrickson mine, the bed is 16 feet thick, contains partings, and is overlain by another bed, 4 feet higher in the section, which is so split by partings as to have little value. At location 140, the open pit south of the river (see Pl. XX, A), the bed is much poorer in quality and more cut up by partings. No further exposures of this zone are met until location 144 is reached, but here only a small amount of coal is to be found at the horizon of the Carbonero.

At locations 68, 70, 141, 142, and 143 a bed 30 to 50 feet above the Carbonero bed was examined. It is from 3 to 4 feet in thickness but at some points contains many partings. At location 141 the coal bed is partly burned and the best section obtainable is probably unreliable on that account.

Section of coal bed at location 141.

	Ft.	in.
Sandstone.		
Coal	6	
Sandstone.....	1	
Coal	6	
Sandstone.		
	1	1

At location 66 a thin coal bed rests upon the Pictured Cliffs sandstone, and at location 140 the same horizon shows coaly material of no value.

South of this district a stretch of several miles is so deeply covered with wind-blown sand and river-terrace materials that exposures are rare, and though coal is probably present, it is not exposed and correlations of the beds are uncertain.

OJO AMARILLO ARROYO.

The coal in and near Ojo Amarillo Arroyo (see Pl. XXIX) occurs in six beds, none of which can be definitely correlated with the beds on San Juan River, though they lie largely in the lower part of the same formation. The lowest bed, about 15 feet above the Pictured Cliffs sandstone, was measured at location 155 as follows:

Section of coal bed at location 155.

Shale.	Ft.	in.
Shale containing gypsum-----	1	1
Shale-----		1
Bone-----		3
Shale.		
	1	5

This bed pinches out both to the north and to the south in a distance of several hundred yards. A similar lens appears at about the same horizon a mile farther south, at location 166, where 1 foot 9 inches of coal is exposed. Overlying it and separated from it by 34 feet of shale is a coal bed which was mapped for several miles and was measured at locations 149, 150, 152, 156, 161, 168, 172, and 175, in the vicinity of Ojo Amarillo Canyon. The bed is best developed south of the arroyo, where an upper bench averages about 4 feet thick. North of the arroyo the bed is split by numerous partings, as shown by sections 149 and 150. The measurements of this bed are shown graphically on Plate XXX.

The next higher bed of coal in the section is represented by measurements at locations 148, 151, 153, and 162. At location 148, about 2 miles north of the arroyo, it shows the following section:

Section of coal bed at location 148.

Shale.	Ft.	in.
Coal-----	1	9
Bone-----		4
Shale.		
	2	1

The bed thins southward to 11 inches at location 149 and to 14 inches at location 153, on the north side of the arroyo. A field test here shows that the coal is impure, containing 16.2 per. cent of ash. South of the arroyo, at location 162, the bed is 13 inches thick, and farther south it thins out and disappears.

Separated from the bed just mentioned by 10 to 20 feet of sandstone and sandy shale is another bed, whose average thickness is less than 3 feet and which was measured at locations 154, 163, and 170. The sections are shown on Plate XXX, except section 163, which contains only 1 foot 6 inches of coal.

South of the arroyo two higher beds which are not present on the north side were examined and measured. One of these was meas-



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ured at locations 159, 164, 167, 169, 171, 174, 176, and 178. The bed is variable in thickness and is split by many partings. It lies 30 feet above the bed of section 154, just mentioned. All the sections are given on Plate XXX except those at locations 159, 164, and 174, which are given below.

Section of coal bed at location 164.

Shale, brown.	Ft.	in.
Coal		3
Bone		3
Coal		3
Bone		7
Shale		$\frac{1}{2}$
Coal	10	
Shale	1	
Sandstone	1	
Coal	1	1
Shale.		
Total section	5	3 $\frac{1}{2}$
Total coal	2	5

Section of coal bed at location 159.

Shale, carbonaceous.	Ft.	in.
Coal		6
Shale, carbonaceous		5
Coal		10
Shale, carbonaceous.		
	1	9

Section of coal bed at location 174.

Shale, carbonaceous.	Ft.	in.
Bone	1	1
Coal, impure		6
Shale		2
Coal		11
Shale.		
	2	8

The highest bed of coal exposed in this locality is a lens whose thickness was obtained at locations 158, 160, 165. It lies about 30 feet above the bed last described. The fact that this is a lens is shown by the middle measurement being 3 feet 10 inches, the northern 2 feet 11 inches (see Pl. XXX), and the southern 1 foot 11 inches.

DIVIDE BETWEEN OJO AMARILLO AND COTTONWOOD ARROYOS.

On the divide between Ojo Amarillo and Cottonwood arroyos, from location 180 to location 206, inclusive (see Pl. XXIX), the coal beds crop out in the bluff facing Chaco River. Two beds are generally of sufficient thickness to be mapped across this district; other

beds are lenticular and are thick enough to warrant mapping only locally.

The lowest lenses mapped lie at the base of the Fruitland formation, and although they are not continuous they occur at the same horizon throughout this portion of the field. These lenses are represented by measurements obtained at locations 191, 194, and 201. At location 191 1 foot 8 inches of coal overlies 10 inches of bone, at location 194 there is 2 feet 2 inches of coal, and at location 201 there is 1 foot 6 inches. These lenses are overlain by 10 to 15 feet of light-yellow sandstone very much like the Pictured Cliffs sandstone below, but because of the presence of coal and the brackish-water fossils similar to those of the Fruitland formation at location 191 these rocks are included in the Fruitland. Above this sandstone is a lens of coal which is very irregular in thickness. At location 180 8 inches of coal overlies 6 inches of bone; at location 183 the same lens contains over 4 feet of good coal. (See Pl. XXX.) This lens is separated by a few feet of gray sandstone and shale from another coal bed which is represented by sections at locations 185, 188, 190, 192, 193, 195, 196, 198, 202, 203, and 206. These sections, except Nos. 196, 202, and 206, are shown on Plate XXX. The bed is very irregular in thickness and in some places is split by many partings. However, it averages over 3 feet of coal. Measurements at locations 196, 202, and 206 are given below:

Section of coal bed at location 196.

Shale.	Ft.	in.
Coal -----	1	5
Shale.		

Section of coal bed at location 202.

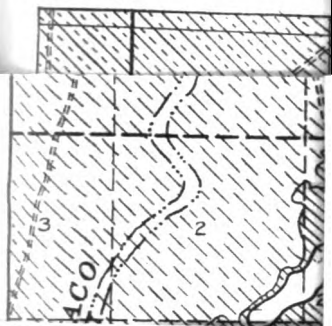
Shale, carbonaceous.	Ft.	in.
Coal, dirty -----	1	0
Shale -----		$\frac{1}{2}$
Coal -----		2
Shale.		
	1	2 $\frac{1}{2}$

Section of coal bed at location 206.

Shale, carbonaceous.	Ft.	in.
Coal -----	1	10
Bone -----		3
Shale, carbonaceous.		
	2	1

From 16 to 18 feet higher is a bed of coal that is more regular and perhaps more persistent than any other bed in this part of the field. It was measured at locations 181, 182, 184, 187, 189, 197, 200, and probably also 204. The sections of this bed show an average thickness of 3 $\frac{1}{2}$ to 4 feet of coal. They are all given on Plate XXX

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R. 17 W.



EXPLANATION

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except No. 204, which shows only 1 foot of coal, and No. 181, which is given below.

Section of coal bed at location 181.

	Ft.	in.
Shale, carbonaceous.		
Coal, containing resin-----	1	2
Shale, carbonaceous-----	1	
Bone-----		6
Shale-----		2
Coal, containing resin-----		5
Shale, carbonaceous.		
Total section-----	3	3
Total coal-----	1	7

This bed is supposed to be the same as the bed at location 178, in the district immediately to the north.

Lenses of coal higher in the formation were measured at locations 186, 199, and 205, representing probably one horizon. Sections 186 and 205 are given on Plate XXX, and 199 is given below:

Section of coal bed at location 199.

	Ft.	in.
Shale, carbonaceous.		
Coal-----		5
Shale-----		1
Coal-----		11
Shale, carbonaceous.		
	1	5

COTTONWOOD ARROYO.

In the Cottonwood Arroyo district there are five coal beds that crop out more or less continuously. These were examined at locations 207 to 251, inclusive. (See Pl. XXIX.) The lowest is at the base of the Fruitland formation and rests directly on the Pictured Cliffs sandstone. Sections of it were measured at locations 209, 212, 216, 224, 225, 234, and 236. With the exception of Nos. 212, 225, and 234, these sections are given graphically on Plate XXX. At location 212 an incomplete section shows more than 1 foot of bony coal; at location 225 the bed contains 1 foot of good coal; and at location 234 it shows 1 foot 3 inches of impure coal. The bed is thickest at location 236, where it consists of a lower bench 3 feet 2 inches thick and a higher one 1 foot 10 inches thick, separated by 3 feet of shale. Farther south these benches are more widely separated and are therefore considered as two distinct beds, though they are mapped as one, owing to the proximity of their outcrops.

Between 40 and 50 feet of cross-bedded gray-white sandstone and gray shale separate this coal bed from the one next above. This upper bed was measured at locations 215, 217, 223, 226, and 237. Sections at locations 217, 223, and 237 are shown on Plate XXX, and those at locations 215 and 226 are given on page 210.

Section of coal bed at location 215.

Shale.	Ft.	in.
Bone-----	1	
Shale-----	1	2
Coal, containing resin-----	1	2
Shale-----		8
Bone-----		4
Shale, carbonaceous.		
Total section-----	3	11
Total coal-----	1	2

Section of coal bed at location 226.

Shale, carbonaceous.	Ft.	in.
Coal-----		9
Shale, carbonaceous-----		8
Sandstone, gray-----	3	
Shale, carbonaceous-----	1	1
Coal-----		8
Bone-----		6
Shale, carbonaceous.		
Total section-----	6	8
Total coal-----	1	5

As can be seen from the sections on Plate XXX, the bed averages over 3 feet in thickness near Cottonwood Arroyo but is split by lignites at the north and south sides of this district.

Between the bed described above and the next bed of importance higher in the section there is about 15 feet of sandy shale. Near top of this shale a thin lens of coal crops out for a short distance north of Cottonwood Arroyo, with the thickness and character shown in the following section:

Section of coal bed at location 208.

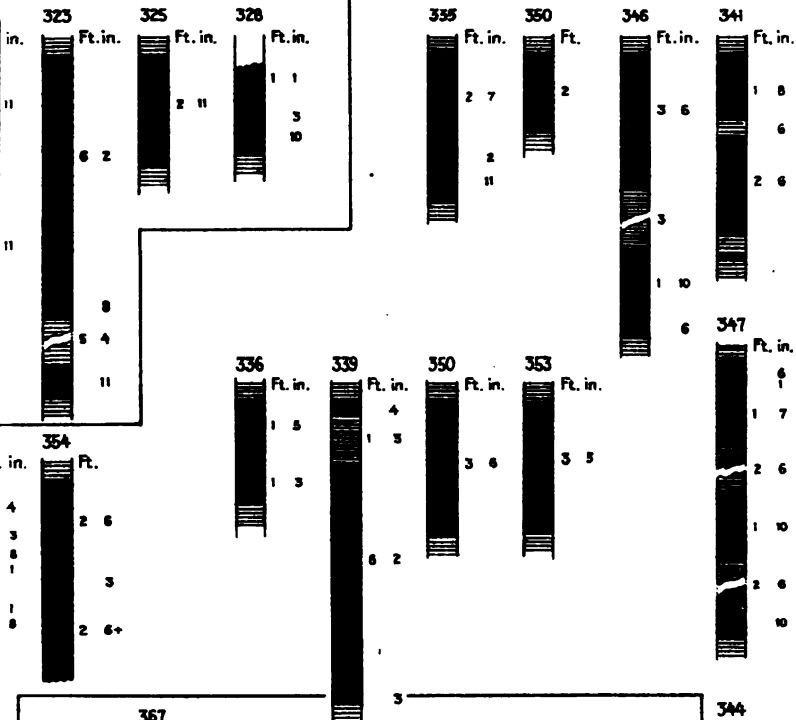
Shale.	Ft.	in.
Coal-----	1	2
Sandstone-----		1
Coal-----		8
Bone-----		4
Coal-----		9
Shale, carbonaceous.		
Total section-----	2	7
Total coal-----	2	2

Section of coal bed at location 210.

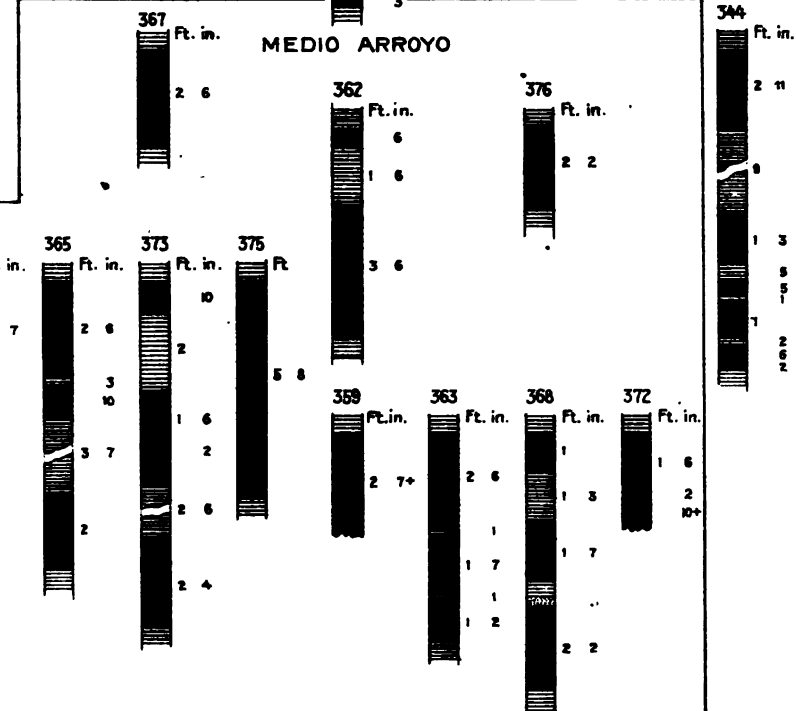
Shale, carbonaceous.	Ft.	in.
Coal-----	1	8
Shale.		

A few feet above this lens lies a bed which has an extensive distribution in this district and the districts to the south. Sections obtained at locations 211, 213, 219, 227, 231, 233, and 238 are shown

BRIMHALL WASH



MEDIO ARROYO



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on Plate XXX; at location 207 it contains only 1 foot 10 inches of coal. It averages $3\frac{1}{2}$ feet in thickness, and it is exceptionally pure at location 233, where it contains over $6\frac{1}{2}$ feet of clean coal.

Another bed of coal which also averages about $3\frac{1}{2}$ feet in thickness lies 30 feet higher in the section. Measurements of it were obtained at locations 214, 218, 220, 228, 230, 232, and 239. These are shown graphically on Plate XXX.

About 70 feet higher lies the highest coal bed of importance in this district. Sections of it at locations 221, 222, 250, and 251 show many partings. As a whole, the bed consists of very impure coal. With the exception of section 221, these measurements are given on Plate XXX.

Section of coal bed at location 221.

Shale, carbonaceous,	Ft.	in.
Bone-----		8
Shale, carbonaceous, with streaks of bone-----	1	6
Shale, gray-----		6
Bone-----	1	7
Shale-----		1
Bone-----		3
Shale-----		1
Bone-----		3
Shale, sandy-----		1
Coal-----		8
Shale-----		2
Coal, containing resin-----		8
Shale, carbonaceous-----		3
Coal-----	1	2
Shale-----		$\frac{1}{2}$
Coal-----		8
Shale.		
Total section-----	8	$7\frac{1}{2}$
Total coal-----	3	2

A lens with a lateral extent of only a few hundred yards occurs midway between this bed and the next one beneath at location 229, where its maximum observed thickness is about $3\frac{1}{2}$ feet. (See Pl. XXX.)

PINA VETA CHINA ARROYO.

Five coal beds exposed at the mouth of Pina Veta China Arroyo are correlated directly with the five beds in the district immediately to the north, and a new bed is present. These beds were examined at locations 240 to 283, inclusive. (See Pl. XXIX.) The lowest bed in Cottonwood Arroyo, as mentioned above, is here a group of two beds and several benches separated by 3 to 15 feet of sandy shale. The two principal beds of the group are thin and irregular, and the coal varies in quality and is commonly high in ash. Measure-

ments of the group obtained at locations 240 and 244 are given below.

Section of coal bed at location 240.

	Ft.	in.
Shale, carbonaceous.		
Coal, much weathered.....	1	0
Shale, carbonaceous.....	3	4
Coal.....	1	1
Shale, carbonaceous.		
Total section.....	5	5
Total coal.....	2	1

Section of coal bed at location 244.

	Ft.	in.
Shale, carbonaceous.		
Coal, impure.....	1	4
Shale, carbonaceous.....	1	8
Coal.....	1	3
Shale, carbonaceous.....	5	5
Coal, impure.....	1	3
Bone.....		10
Total section.....	11	9
Total coal.....	3	10

Only one bench of coal 1 foot 6 inches thick was observed at location 252, and one 1 foot 8 inches thick at location 253.

The next coal bed, 35 feet higher in the section, was measured at locations 241, 243, 247, 254, 258, 259, and 263, as shown on Plate XXX. In these sections it averages about 4 feet in thickness, but at location 241, as shown below, it has one bench over 4 feet thick and two other benches which are separated by thick partings.

Section of coal bed at location 241.

	Ft.	in.
Shale, carbonaceous.		
Coal.....	4	10
Shale.....	1	3
Bone.....		6
Coal.....	1	6
Shale.....	1	8
Bone.....		2
Coal, impure.....	1	2
Shale.		
Total section.....	11	1
Total coal.....	7	6

This bed contains a large quantity of coal, its maximum thickness (at location 259) being 7 feet 10 inches.

About 15 feet above the coal bed just described is the bed which is thought to be the same as the one measured at location 238, in the district to the north. Measurements of this bed were obtained at

locations 242, 245, 246, 248, 255, and 260 and are shown graphically on Plate XXX. The bed is very irregular, its minimum observed thickness, at location 248, being 2 feet 9 inches, of which 10 inches is bone and shale, and its maximum observed thickness, at location 245, being 6 feet 2 inches of coal. However, the upper bench at location 245 contains a high percentage of ash.

The next higher coal bed in the section is the same as the one measured at location 239, in the district immediately to the north. Measurements of it were obtained at locations 249, 261, and 266. This bed averages 2½ feet, but at location 261 it is split into two benches by a parting which is over 4 feet thick, as shown in the following section:

Section of coal beds at location 261.

Shale.	Ft.	in.
Coal	11	
Sandstone	1	
Shale, carbonaceous	5	
Shale	3	9
Coal	1	3
Total section	6	5
Total coal	2	2

The other sections of this bed are shown on Plate XXX.

Near location 261 a bed of coal appears midway between the bed just described and the highest bed in the section. It was measured at locations 262, 271, 275, 267, and 270 and was found to contain many partings, as shown in the sections on Plate XXX.

The highest bed in this district is the same as that measured at location 251, in the district to the north. Measurements of it at locations 256, 257, 283, and 269 are given on Plate XXX; at location 268 it contains 2 feet 1 inch of good coal. This bed averages nearly 4 feet in thickness.

KLAYCHIN ARROYO.

Very good exposures of the Pictured Cliffs and Fruitland formations are to be found on Klaychin Arroyo between locations 264 and 314 (see Pl. XXIX), and the coal beds can be measured in considerable detail except where they have burned along their outcrops and are now covered with red baked shale or clinker. The following section extending from location 284 to location 287 gives the thickness and character of most of the coal beds, as well as the intervening sandstone and shale, and indicates the great amount of coal here present in the Fruitland formation;

Section on Klaychin Arroyo, compiled from sections 284, 285, 286, 287, 315, and 320.

Sandstone, gray.		Ft.	in.
Shale, brown	-----	3	
Highest or seventh bed:			
Coal	-----	1	
Shale, brown, carbonaceous	-----	1	3
Coal	-----		10
Sandstone, yellow	-----	2	
Coal	-----		4
Shale, brown and gray	-----	12	
Sandstone	-----	8	
Shale, drab, sandy	-----	7	
Shale, brown, carbonaceous	-----	2	
Sixth bed:			
Coal	-----	1	10
Shale, brown, carbonaceous	-----	1	6
Coal	-----		10
Sandstone, gray, carbonaceous	-----		4
Coal, impure	-----		3
Shale, brown, sandy	-----	1	
Coal	-----		3
Sandstone, brown, carbonaceous	-----		6
Coal, with resin	-----	2	7
Shale, carbonaceous	-----		3
Coal	-----	1	6
Shale, black, carbonaceous	-----		1
Coal, with resin	-----	1	6
Sandstone, gray, carbonaceous	-----		4
Coal	-----		6
Shale, brown	-----	1	6
Sandstone, platy, brown	-----		4
Shale, burned red and white	-----	10	
Fifth bed:			
Ash (from burned coal bed)	-----		6
Shale, banded brown and gray	-----	5	
Sandstone, buff, platy, lenticular	-----	1	
Shale, greenish gray, sandy	-----	7	
Fourth bed:			
Coal	-----	1	3
Shale, sandy	-----		2
Coal	-----	2	3
Shale, brown, carbonaceous	-----		$\frac{1}{2}$
Coal	-----	1	3
Shale, brown	-----		5
Coal, containing resin	-----	1	3
Shale, brown, sandy	-----	7	
Shale, black, carbonaceous	-----	1	6
Third bed:			
Coal	-----	1	6
Bone	-----		1
Shale, brown, very sandy	-----		3
Coal, containing much resin	-----	5	6

	Ft.	in.
Shale, brown, carbonaceous.....	2	
Sandstone, brown, platy.....	2	
Shale, brown, carbonaceous.....	1	
Second bed:		
Coal.....	1	3
Shale, brown.....	2	6
Lowest bed:		
Coal.....	2	11
Shale, brown.....	1	
Coal.....	2	7
Bone.....		3
Coal.....	2	8
Shale, brown, carbonaceous.....	2	
Pictured Cliffs sandstone.....		
Total thickness.....	121	4
Total coal.....	34	8

The lowest bed of coal is the same as the lowest one in Pina Veta China Arroyo. It measured at locations 272, 273, 278, 282, 284, 292, 293, 294, and 300. The sections at locations 273, 278, and 293 are given below; others are shown on Plate XXX. Its variability in thickness and character is marked.

Section of coal bed at location 273.

	Ft.	in.
Shale.....		
Coal.....	1	9
Shale.....		

Section of coal bed at location 278.

	Ft.	in.
Shale.....		
Coal.....	2	4
Shale.....	1	6
Coal.....	2	8
Shale.....	3	4
Coal.....	1	10
Shale.....		
Total section.....	11	8
Total coal.....	6	10

Section of coal bed at location 293.

	Ft.	in.
Shale.....		
Coal.....	1	9
Shale.....		

The second bed, as shown in the section on this page, is 1 foot 3 inches thick and only 2½ feet above the lowest bed at location 284. Apparently it is a thin lens which extends only a short distance.

The third bed averages nearly 4 feet in thickness and is correlated with that measured at location 263, in the district immediately to the north. Measurements of it were obtained at locations 264, 274, 281, 285, 290, 291, 298, 307, 302, and 310. Except the sections at locations 290 and 291 these are given on Plate XXX. At location 290 all the

beds are burned and their outcrops are covered with baked shale and clinker, and at location 291 the bed contains only 1 foot 3 inches of coal. South of this point this bed is thin and does not warrant mapping.

The fourth coal bed is split by many partings, as shown particularly at location 297. It is represented by sections at locations 277, 280, 286, 296, 297, 303, 306, 311, 313, and 314. With the exception of those at locations 311 and 313, all are shown on Plate XXX. Although sections 311 and 313 are separated by less than a quarter of a mile they differ much and illustrate the great variability of some of the coal beds of the Fruitland formation. At location 311 the bed contains only 1 foot 9 inches of coal, but at location 313 it contains 5 feet 6 inches of coal of fair quality, though considerably weathered where measured. The other measurements show an average thickness of about 4 feet for this bed.

The fifth coal bed, which is 12 to 15 feet higher than the one last mentioned, was measured at locations 276, 279, 287, 295, 299, 304, 308, and 312. The sections not shown on Plate XXX are given below.

Section of coal bed at location 299.

Shale, brown, sandy.	Ft.	in.
Coal	1	9
Shale, carbonaceous.		

Section of coal bed at location 308.

Shale.	Ft.	in.
Coal, weathered	1	0
Shale.		

At location 287 the bed has been burned and is represented by a 6-inch bed of ash.

The next higher coal bed in the section was measured at locations 289, 305, 309, 315, and 319. It averages over 4 feet of coal. These sections are given on Plate XXX, except the one which follows.

Section of coal bed at location 315.

Shale, carbonaceous.	Ft.	in.
Coal, good	1	10
Shale, carbonaceous	1	6
Coal		10
Sandstone, gray		4
Coal, impure		3
Shale, sandy	1	
Coal		3
Sandstone		6
Coal; contains much resin	2	7
Shale, carbonaceous		3
Coal	1	6
Shale, black		1

Shale, carbonaceous—Continued.	Ft.	in.
Coal; contains resin-----	1	6
Sandstone, gray-----		4
Coal, good-----		6
Shale, carbonaceous.		
Total section-----	13	3
Total coal-----	9	2

The seventh or highest coal bed in the Fruitland formation in this locality is correlated with the highest coal bed in Pina Veta China Arroyo, which was measured at location 283. This bed is mined on a small scale by stripping at location 301, where it contains an upper bench 3 feet thick and a lower bench $2\frac{1}{2}$ feet thick. Technically these two benches are distinct beds, for they are separated by about 7 feet of shale. However, they are worked together at this place and are parts of the same bed to the north and to the south. A sample was obtained from the lower bed at this location, and an analysis of it is given on page 185 (No. 22685). The bed is only about 2 feet thick at location 320, as shown in section on Plate XXX.

DIVIDE BETWEEN KLAYCHIN ARROYO AND BRIMHALL WASH.

On the divide between Klaychin Arroyo and Brimhall Wash the lower coal beds crop out in a low bluff extending in a nearly north-south direction. The higher beds, on the other hand, are concealed in the broad, low divide and can be seen only about low hills or in "blowouts" where the wind has removed the loose surface material. The district extends from location 316 to location 333. (See Pl. XXIX.)

The lowest coal bed is at nearly the same horizon as the lowest in the district immediately to the north. It is represented by a series of lenses and was measured at locations 316, 327, and 332. Between these three localities the bed is less than 1 foot thick. Sections at locations 316 and 327 are shown on Plate XXX, and that at location 332 is given here:

Section of coal bed at location 332.

Shale, sandy.	Ft.	in.
Coal-----	1	2
Shale, carbonaceous.		

The coal bed next higher in the section is the same as the one measured at location 314. Sections of it at locations 321, 322, 329, 331, and 333 are given on Plate XXX; at location 317 the bed is burned and shows 1 foot of ash. The average thickness of this coal bed in this district is nearly 4 feet.

The third bed of importance in this district is represented by sections at locations 318, 323, 324, 325, 328, and 330. In the north-

ern part of the district it is in reality two beds, the parts being separated by 5 feet of shale, but each bench is thick enough to be valuable. The sections are all given on Plate XXX, except that at location 330, which is given here.

Section of coal bed at location 330.

Shale, carbonaceous.	Ft.	in.
Coal, impure.....		10
Bone, sandy.....		1
Coal, impure.....		8
Shale, carbonaceous.....		1
Coal.....		4
Bone.....		4
Coal.....	1	4
Bone.....		2
Coal.....	1	3
Bone.....		2
Coal, impure.....		11
Shale, black.....		8
Coal, impure.....		7
Bone.....		4
Coal, impure.....		4
Shale, carbonaceous.		
Total section.....	7	8
Total coal.....	6	3

About 6 feet below this section is a lens containing 1 foot 6 inches of coal. Also, 15 feet higher than the bed just described, at location 326, a lens crops out which contains nearly 5 feet of coal, but it thins within a short distance to the north and south of this point.

Two coal beds which are present in the district to the north are believed to be present in this district also, but owing to the evenness of the surface of the divide they are not exposed. It is believed, however, that they crop out on Brimhall Wash, and they will be considered in the following description of that district.

BRIMHALL WASH.

The exposures in Brimhall Wash are not as good as those in Klaychin Arroyo, to the north, but the horizons of the coal beds can be followed between outcrops by the occasional clinker hills and by weathered coal thrown out from gopher holes.

Five coal beds were mapped in this part of the field, which extends from location 334 to location 344. (See Pl. XXIX.) The lowest bed in the section was measured at locations 334, 335, 337, 341, 342, 343, 346, 348, and 350. It contains on the average about $2\frac{1}{2}$ feet of coal, and its thickest observed section is at location 346, where it contains $3\frac{1}{2}$ feet of coal, as well as a lens 3 feet lower carrying 1 foot 10 inches of coal. Sections at locations 335, 341, 346, and 350 are shown on Plate XXX; the others are given on page 219,

Section of coal bed at location 334.

Shale, carbonaceous.	Ft.	in.
Bone and ash-----	1	3
Shale, carbonaceous.		

Section of coal bed at location 337.

Shale, carbonaceous.	Ft.	in.
Coal-----	1	6
Shale, carbonaceous.		

Section of coal beds at location 342.

Shale.	Ft.	in.
Coal-----		6
Bone-----		1
Coal-----		10
Bone-----		5
Shale, sandy-----	15	
Coal-----	1	
Clay-----		6
Coal-----	1	1
Shale-----	4	9
Coal-----		6
Bone-----	1	6
Shale-----	1	2
Coal-----	2	
Shale.		
Total section-----	29	4
Total coal-----	5	11

Section of coal beds at location 343.

Shale, carbonaceous.	Ft.	in.
Coal-----	1	4
Bone-----	1	5
Shale, carbonaceous-----	6	
Coal, good-----	1	1
Bone-----		4
Coal-----		4
Shale, carbonaceous.		
Total section-----	10	6
Total coal-----	2	9

Section of coal bed at location 348.

Shale.	Ft.	in.
Coal; contains resin-----	1	6
Shale.		

Above this bed and separated from it by about 18 feet of sandy shale is a coal bed which is correlated with that measured at location 330. Measurements of it in this district were obtained at locations 345, 347, and 349. The upper part of the section at location 342 (see above) may also represent this horizon, though the connection is not

traceable. This bed is thinner here than in the district to the north, and at location 347 it is associated with two lenses of coal, as shown on Plate XXX. At location 345 it contains 1 foot 6 inches of coal, and at location 349 there is 1 foot 8 inches of coal overlain by 5 inches of bone.

About 20 feet higher in the section is a coal bed represented by sections 340, 351, and 354, which are shown on Plate XXX. Its average thickness in this district is about $5\frac{1}{2}$ feet.

The bed last mentioned is separated by about 10 feet of shale from the next higher one, which was measured at locations 336, 339, 352, and 353. This bed averages $3\frac{1}{2}$ feet in thickness, as shown by the sections on Plate XXX.

The highest traceable coal bed on Brimhall Wash is represented only by section 344 (Pl. XXX), though a thin lens containing about 1 foot of coal mapped half a mile east of location 339 may be correlated with it. Its horizon at some points is marked by clinker.

A coal bed observed at location 338 has a thickness of 1 foot 2 inches but is of very small lateral extent. Its horizon is well up in the Fruitland formation, above the other coal beds.

MEDIO ARROYO.

In the Medio Arroyo district, extending from location 355 to location 375, the coal beds, instead of having the usual eastward dip, are affected by a local syncline and anticline. As shown on the map (Pl. XXIX), the dips are low, mainly less than 2° . Nevertheless the outcrop and attitude of the beds are modified by this structure. The syncline is oval and has a northeasterly axis about 5 miles in length and a shorter axis about $3\frac{1}{2}$ miles long. Calculations from elevations on the eastern limb of the syncline give a westward dip of 80 feet to the mile. Other dips are shown on Plate XXIX.

The lowest coal bed in the section was measured at locations 355, 357, 365, 373, and 375. The bed is the same as the lowest coal on Brimhall Wash. At locations 365 and 373 a lower bench is separated from the upper by 3 feet 7 inches and 2 feet 6 inches respectively of shale, but at location 375 there is no shale parting. The sections are given graphically on Plate XXX.

The next higher bed of coal was measured at locations 364, 366, 370, and 374. These measurements are given below.

Section of coal bed at location 366.

Shale, carbonaceous.	Ft.	in.
Coal; contains resin.....	1	11
Shale.		

Section of coal bed at location 370.

Shale, brown.	Ft.	in.
Coal; contains resin-----	1	5
Shale, brown-----		10
Coal-----		8
Shale.		
	2	11

Section of coal bed at location 374.

Shale, brown.	Ft.	in.
Coal-----	1	11
Bone-----		3
Shale, drab.		
	2	2

Section of coal bed at location 384.

Shale, carbonaceous.	Ft.	in.
Coal-----	1	7
Shale-----		3
Coal-----		8
Shale.		
	2	6

An isolated coal outcrop occurs in a butte at location 356, and another around a butte at location 358. These outcrops are about 25 feet above the bed last described and are apparently at the same horizon, though the thickness is very different in the two localities. Section 356 is given on Plate XXX, and section 358 is given below:

Section of coal bed at location 358.

Shale, carbonaceous.	Ft.	in.
Coal; contains resin-----	1	11
Bone-----		6
Coal, impure-----		3
Shale.		
	2	8

A lens of coal probably a few feet above the horizon just described was measured at location 369, where it contains 3 feet 4 inches of impure coal.

The next coal bed lies 5 feet above this one and is represented by sections at locations 359, 363, 368, and 372. These are shown on Plate XXX. The bed averages about 3½ inches in thickness.

Another coal bed from 5 to 15 feet higher is represented by sections at locations 361, 367, and 371:

Section of coal bed at location 361.

Shale.	Ft.	in.
Coal-----	1	11
Shale.		

Section of coal bed at location 367.

Shale.	Ft.	in.
Coal-----	2	6
Shale, carbonaceous.		

Section of coal bed at location 371.

Shale.	Ft.	in.
Coal, dirty-----		6
Shale, carbonaceous-----	1	8
Coal-----	1	3
Shale.		
	3	5

The outcrops as well as the mass of the two beds just mentioned are close together at some points, and it is probable that the two beds could be worked at the same time in a number of places.

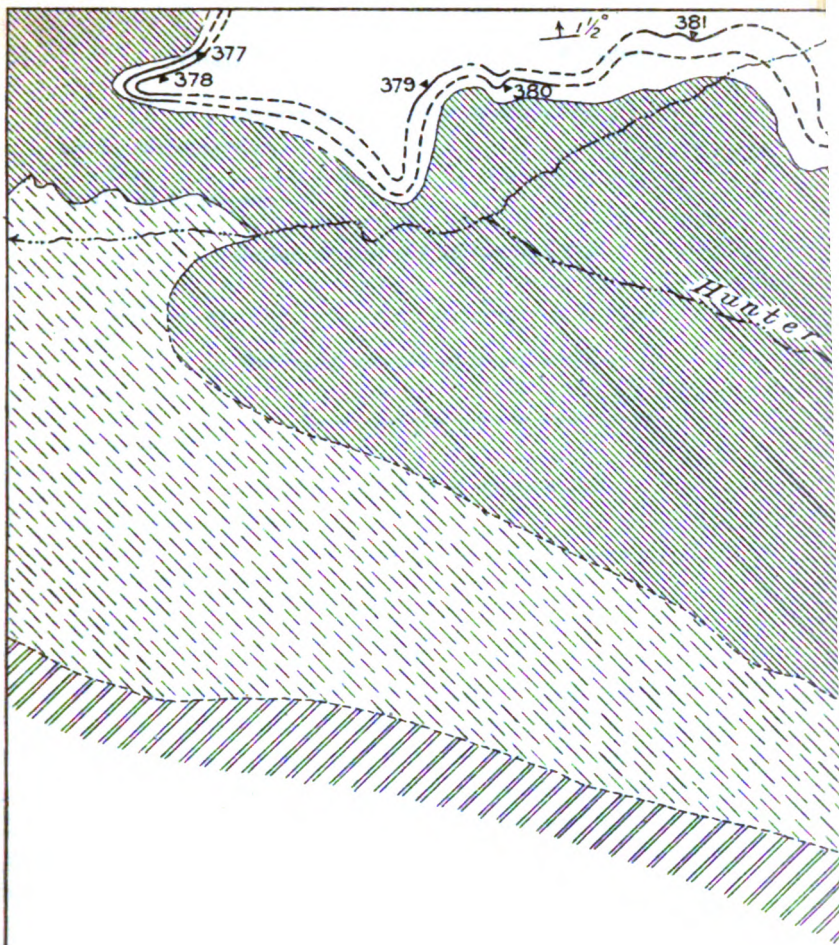
Another pair of coal beds occurs about 20 feet higher. The lower one of the two was measured at location 360, and the section is given on Plate XXX. The bed at this place shows over 7 feet of good coal but is a comparatively short lens and thins within short distances to the north and to the south. The higher bed was measured at location 362, where it contains 3 feet 6 inches of coal. From its outcrop it also is believed to be lenticular, though exposures of it to the south are not good. Measurements obtained at location 376, giving 1 foot 3 inches of coal separated by $6\frac{1}{2}$ feet of shale from 2 feet 2 inches of coal below, may represent the two beds last described, though the correlation is not certain.

LOWER HUNTER WASH.

Along Hunter Wash from location 277 to location 404 (see Pl. XXXI) the coal crops out on the north side of the arroyo and strikes about S. 80° E. The dip is N. 10° E., about $1\frac{1}{2}^{\circ}$ throughout the district. Two valuable coal beds were observed and mapped most of the distance of 12 miles. The correlations between outcrops were based largely on the stratigraphic position. Between these beds in several localities are one or two lenses which extend only for short distances along the outcrop.

The lowest coal bed has in this district an average thickness of about 5 feet. Measurements of it at locations 377, 380, 384, 385, 388, 400, 401, 402, and 404 are given on Plate XXXII; at location 392 the bed contains only 1 foot 10 inches of coal.

A higher bed, which is very persistent and has a distribution almost equal to that of the lowest bed, was measured at locations 378, 379, 381, 382, 386, 387, 390, 391, 394, 395, and possibly 403. Between locations 395 and 403 the connection can not be traced, but the horizon of the coal is the same at both places. The bed is regular in thickness compared with the other coal beds of the field, although its average is less than 3 feet. If the coal at location 403 is the same bed it is much thicker farther east and south. Sections at locations 378, 394, 395, and 403 are given below; the others are shown on Plate XXXII.



Section of coal bed at location 373.

Shale, carbonaceous.	Ft.	in.
Coal -----	1	10
Shale, carbonaceous.		

Section of coal bed at location 394.

Shale.	Ft.	in.
Coal -----	1	6
Shale.		

Section of coal bed at location 395.

Shale.	Ft.	in.
Coal -----	1	6
Shale, sandy.		

Section of coal bed at location 403.

Shale, carbonaceous.	Ft.	in.
Coal -----	2	4
Shale -----		1
Coal -----	1	9
Sandstone.		
	4	2

In the breaks south and southwest of the reservoir shown on Plate XXXI three coal lenses or beds, which have only a small length of outcrop, appear between the two beds just described. Sections of these lenses were obtained at locations 383, 389, 396, 397, 398, and 399. At location 383 1 foot 2 inches of coal was found, and at location 389 the same thickness was exposed. The other sections are given graphically on Plate XXXII.

UPPER HUNTER WASH.

The upper Hunter Wash district is continuous with that just described, but owing to the excellence of its exposures it is treated by itself. (See Pl. XXXI.) The district is a much dissected badland with very little vegetation and affords an excellent opportunity to examine the coal in considerable detail. It seems probable that the divide between Hunter Wash and Medio Creek contains beneath its flat sandy surface at least some of the higher beds which crop out in the Hunter Wash badlands and that these should be correlated with those high up on Medio Arroyo. Nevertheless, because of the lack of exposures on the gently sloping surface of the divide, due in part to the quantity of wind-blown sand on it, no correlation will be attempted. It is known, however, that several of the coal beds mapped on Hunter Wash do not extend beneath the divide with a thickness worth considering. These are indicated by the measured sections.

Six coal beds and two small lenses thicker than 14 inches were mapped in this district. The lowest one has a maximum observed

thickness of 12 feet 9 inches at location 419, where a sample was also taken for analysis (No. 22807, p. 185). Sections of this bed were obtained at locations 403, 419, 422, 454, 456, 458, 460, 462, 463, 464, 465, 466, and 467, all of which are shown on Plate XXXII. This bed has been burned throughout an area of about 2 square miles just south of Hunter Wash, and an enormous mass of red and varicolored clinker flanks the arroyos. In some places the clinker is 40 to 50 feet thick and shows the effect of great heat.

At locations 405, 411, 412, and 420 measurements were taken of thin, irregular beds 30 to 60 feet higher stratigraphically, which, owing to the discontinuity of the outcrop and the variable thickness, can not be correlated with certainty and are therefore called lenses, though they occur near the same horizon. Sections at locations 405 and 411 showing 2 feet and 2 feet 4 inches of coal, respectively, are given on Plate XXXII. Sections at locations 412 and 420 are given below:

Section of coal bed at location 412.

Shale, carbonaceous.	Ft.	in.
Coal, very impure-----		5
Coal, with resin-----	1	
Shale.		
	1	5

Section of coal bed at location 420.

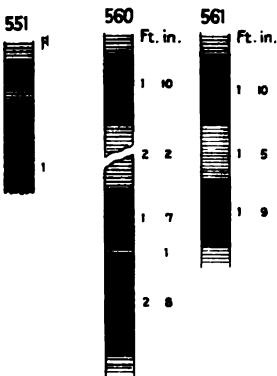
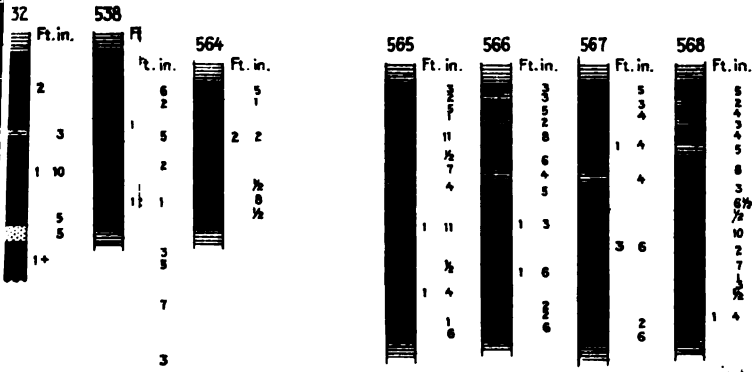
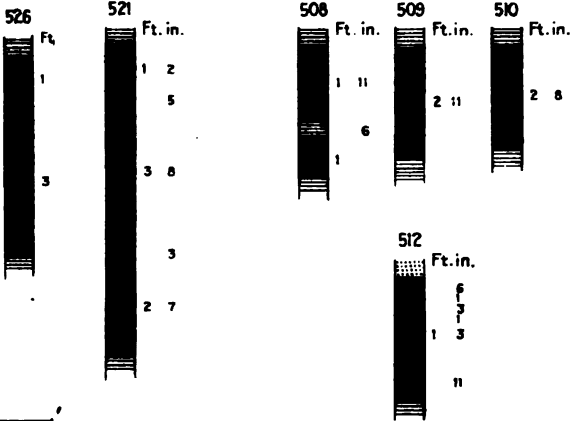
Shale.	Ft.	in.
Bone-----		2
Coal-----		6
Bone-----		5
Coal-----		5
Sandstone, gray, clayey-----	10	6
Coal-----		8
Shale, gray-----	14	6
Coal-----		11
Sandstone, gray-white.		
Total section-----	28	1
Total coal-----	2	6

A bed measured at locations 455, 457, 459, and 461 crops out on the divide on the south side of Hunter Wash and probably is very near the horizon of the lenses just described. The sections shown on Plate XXXII and the one given below indicate its variable character and the large number of partings it contains.

Section of coal bed at location 461.

Shale, carbonaceous.	Ft.	in.
Bone-----		8
Shale-----	1	3
Coal, impure-----	1	2
Bone-----		4
Shale.		
	3	5

BULLETIN 716 PLATE XXXII



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Another coal bed about 80 feet above the lowest bed was measured at locations 406, 408, 410, 416, 421, 423, 441, 443, 447, 453, and 451. The bed averages about $4\frac{1}{2}$ feet in thickness but contains many partings, which in places make it practically worthless. With the exception of those at locations 406, 408, and 416, the sections are given graphically on Plate XXXII.

Section of coal bed at location 406.

Sandstone.	Ft.	in.
Coal-----	10	
Shale-----	1	
Coal, impure-----	8	
Shale, sandy-----	3	
Coal-----	1	3
Shale.		
Total section-----	3	1
Total coal-----	2	9

Section of coal bed at location 408.

Shale.	Ft.	in.
Coal-----	8	
Shale.		

Section of coal bed at location 416.

Shale, carbonaceous.	Ft.	in.
Coal-----	8	
Bone-----	1	
Coal-----	11	
Shale.		
	1	8

Separated from this bed by about 15 feet of shale and sandy shale is a coal bed which was measured at locations 407, 409, 413, 415, 418, 424, 425, 431, 432, 437, 442, 446, 450, and 452. This bed also is very impure and filled with many shale and bone partings. The only locality at which it shows no partings is in the vicinity of locations 437 and 442, where it contains over 4 feet of clear coal. Sections at locations 446 and 450 are given here; the other sections are shown on Plate XXXII.

Section of coal bed at location 446.

Sandstone.	Ft.	in.
Coal-----	2	6
Shale, carbonaceous-----	5	
Coal-----	6	
Shale.		
Total section-----	8	
Total coal-----	3	

Section of coal bed at location 450.

Shale, carbonaceous.	Ft.	in.
Coal, impure		8
Shale		5
Coal		5
Shale		$\frac{1}{2}$
Coal	1	8
Shale.		
Total section	3	2 $\frac{1}{2}$
Total coal	2	9

A thin but persistent coal bed about 25 feet higher in the section was measured at locations 414, 427, 434, 436, 439, and 449. The thickest portion of the bed observed is at location 414, where it contains 3 feet 4 inches of coal. At location 427 it contains 1 foot 3 inches of coal; at 434, 1 foot 7 inches; at 436, 1 foot 3 inches; and at 449, 1 foot 7 inches. Sections 414 and 439 are shown on Plate XXXII.

A bed that crops out on the south fork of Hunter Wash about 10 feet above the bed just described was measured at locations 428, 433, 435, 438, 445, and 448. The bed averages less than 2 feet in thickness, and therefore the sections are all given in the text.

Section of coal bed at location 428.

Shale, carbonaceous.	Ft.	in.
Coal; contains resin	1	
Sandstone		2
Coal; contains resin	1	
Shale.		
	2	2

Section of coal bed at location 433.

Shale, carbonaceous.	Ft.	in.
Coal; contains resin	1	
Sandstone		2
Coal; contains resin		10
Shale, carbonaceous.		
	2	

Section of coal bed at location 435.

Shale, carbonaceous.	Ft.	in.
Coal		.8
Sandstone		2
Coal; contains resin		10
Shale, carbonaceous.		
	1	8

Section of coal bed at location 438.

Shale, sandy.	Ft.	in.
Coal		3
Shale, carbonaceous		4
Coal		10
Shale		1

Shale, sandy—Continued.	Ft.	in.
Coal; contains resin-----	1	7
Bone-----		9
Coal; contains resin-----	1	1
Bone-----		5
Shale.		
Total section-----	5	4
Total coal-----	3	9

Section of coal bed at location 445.

Shale, carbonaceous.	Ft.	in.
Coal-----	1	8
Sandstone-----		2
Coal-----		9
Shale.		
	2	7

Section of coal bed at location 448.

Shale, carbonaceous.	Ft.	in.
Coal-----		10
Sandstone-----		2
Coal-----	1	3
Shale.		
	2	3

The highest coal bed of value on Hunter Wash has an average thickness of about $3\frac{1}{2}$ feet, though the upper and lower portions of the bed contain many partings of shale and bone. Measurements of it were obtained at locations 417, 426, 429, 430, 440, and 444, all of which are given graphically on Plate XXXII.

COAL CREEK.

The coal on Coal Creek is neither so abundant nor so well exposed as it is on Hunter Wash. (See Pl. XXXI.) The beds, with the exception of the two lower ones, can not be correlated certainly with those that crop out on Hunter Wash. These two lower beds, however, are believed to be continuous with the corresponding beds in the district to the north. The lowest coal bed is the best one in this district, having an average thickness of 4 feet. It was measured at locations 469, 470, 472, 473, 474, 475, 476, and 478. With the exception of the sections given below the measurements are shown graphically on Plate XXXII.

Section of coal bed at location 475.

Shale, carbonaceous.	Ft.	in.
Coal-----	1	3
Shale.		

Section of coal bed at location 476.

Shale, carbonaceous.	Ft.	in.
Coal, impure-----	1	6
Bone-----	1	2
Shale,		
	2	8

Separated from this bed by 5 to 20 feet of sandy shale is a higher coal correlated with the second bed on Hunter Wash. It is thin and variable here also, as shown by sections 468 and 471 on Plate XXXII. It was noted east of location 471 at several points but is less than a foot thick.

Four coal beds higher in the section were measured on Ojo Alamo Arroyo near the point where it joins Coal Creek. The lowest one of these was measured at locations 477, 480, and 490. This bed is very pure in the vicinity of location 480, where it contains 5 feet 7 inches of clear coal. However, it does not persist very far along the outcrop, and to the south it is concealed in the flat valley of Coal Creek. Sections 480 and 490 are shown on Plate XXXII.

Section of coal bed at location 477.

	Ft.	in.
Shale, carbonaceous.		
Bone.....	1	4
Coal, weathered.....	1	2
Shale, carbonaceous.....	6	
Coal.....		6
Shale.....		6
Coal.....		8
Shale, brown.....		1
Coal, impure.....	1	6
Shale, brown.		
Total section.....	11	3
Total coal.....	3	10

The next higher bed was measured at locations 479, 481, 482, 487, and 489. It is believed to continue southward across Coal Creek and is correlated with the bed at location 506. It averages about 3 feet in thickness, as shown by the sections on Plate XXXII and those given below. At location 479 only 6 inches of coal is exposed, but at location 482 over 6 feet was found.

Section of coal bed at location 482.

	Ft.	in.
Top eroded.		
Coal, weathered.....	1	1
Shale.....		1
Coal.....	1	4
Shale.....		1
Coal.....	2	3
Shale, brown.....	1	8
Coal.....	1	
Shale.....		6
Coal.....		11
Shale.....		1
Coal.....		10
Shale.....		6
Coal.....		10
Shale.		
Total section.....	11	1½
Total coal.....	8	3

Sections at locations 484, 486, and 488 represent the coal bed next above. At location 486 the bed contains 1 foot 2 inches of coal. The other sections are shown on Plate XXXII.

The highest coal bed could be traced for only a short distance. Section 483, on Plate XXXII, shows three benches, each a little over 1 foot thick, separated by thin shale partings.

Three coal beds crop out in an isolated tract on the south side of Coal Creek. They probably correspond with the lower three beds on the north side of the creek, but the correlation is not certain, as the beds are known to be lenticular. The lowest bed was measured at locations 492, 494, 496, 498, 500, 503. Its greatest thickness is at location 500, where it contains 5½ feet of coal. The section at location 492 shows only 1 foot; at 494, 1 foot 2 inches; and at 496, only 10 inches. Sections at locations 500 and 503 are shown on Plate XXXII.

Section of coal bed at location 498.

Sandstone, gray.	Ft.	in.
Bone-----	1	2
Coal-----	1	4
Shale.		
	2	6

The thickness of the second coal bed, which is about 15 feet higher, was obtained at locations 491, 493, 495, 497, 499, 502, 504, and 505. This bed averages about 4½ feet of coal. The measurements at locations 491 and 502 are given below; the others are shown on Plate XXXII.

Section of coal bed at location 491.

Shale.	Ft.	in.
Coal-----		11
Shale, sandy.		

Section of coal bed at location 502.

Shale.	Ft.	in.
Bone-----		6
Sandstone-----		8
Coal-----	3	11
Shale, sandy.		
	4	8

The bed when visited in September, 1915, was burning at a point a short distance east of location 493. Although little smoke was noticed, gases were issuing from crevices over the outcrop, and many slumps of the overlying beds had taken place recently. Red clinker or baked sandstone and shale are abundant at this locality. The highest portion of this outlier contains a small area (see Pl. XXXI) underlain by another bed, which was measured at location 501.

Section of coal bed at location 501.

	Ft.	in.
Shale, brown.		
Coal		8
Shale, brown		8
Coal	1	6
Shale, brown.		
	2	10

BETWEEN BLACK LAKE CANYON AND SPLITLIP FLAT.

In this district between Black Lake Canyon and Splitlip Flat (see Pl. XXXIII) several coal beds are exposed, but owing to the lack of continuous exposures it is very difficult to correlate the beds at different horizons. The most probable correlation of outcrops gives five beds, with a possibility of six.

In the beds of Black Lake and several other small intermittent lakes in this vicinity there are deposits of black material buried beneath several feet of sand and clay. These deposits were described at considerable length a few years ago.¹⁸ In the writers' opinion this substance is a peat and may represent a period when these lakes were permanent throughout the year.

The lowest bed of the Fruitland formation crops out in a bluff just north of Black Lake Canyon, 2 miles west of Black Lake. It was measured at location 528, where it contains about 5 feet of coal. (See Pl. XXXII.)

The second bed crops out in the same bluff about 20 feet higher and was measured at locations 522, 526, and 527. It is probably much more extensive than is indicated by the outcrop line on Plate XXXIII, but it is concealed in the broad flats by soil and wind-blown sand. Its thickness averages nearly 4 feet where observed, as shown by the sections on Plate XXXII.

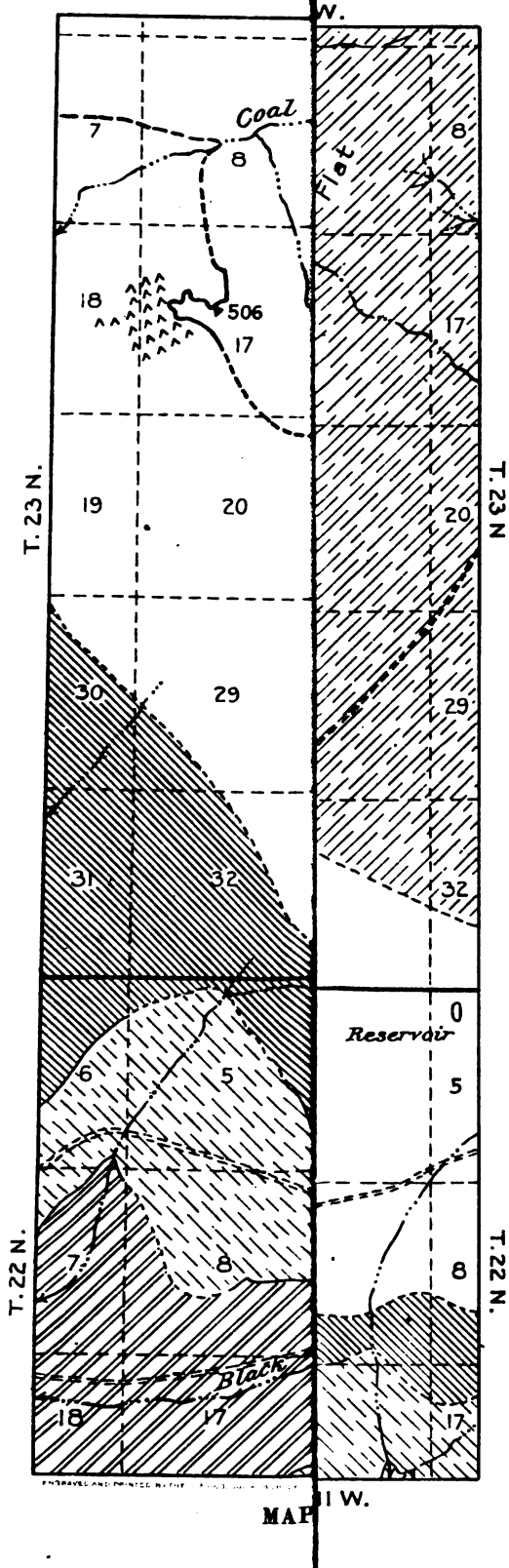
The next higher coal bed was measured at locations 514, 516, 523, 524, and 525. The average thickness of this bed is nearly 3 feet. The section at location 524 is given below; the other measurements are shown on Plate XXXII.

Section of coal bed at location 524.

	Ft.	in.
Sandstone, yellow.		
Coal, impure		11
Shale, carbonaceous		3
Bone		5
Shale, carbonaceous.		
	1	7

A coal bed from 15 to 20 feet higher than the one just described is correlated with the bed measured at location 506. This bed was measured at locations 511, 515, 517, 518, 519, and 521. (See Pl.

¹⁸ Foster, William, Remarkable carbonaceous deposit near Putnam, N. Mex.: *Econ. Geology*, vol. 8, p. 380, 1913.



EXPLANATION

- | | | |
|------------------|--|------------|
| Upper Cretaceous | | CRETACEOUS |
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XXXII.) Although this bed averages more than 5 feet of coal, it is split by many partings, and in only a few localities are there benches of clean coal as thick as 3 feet. A lens at about the same horizon was measured at location 507, where it contains 1 foot 4 inches of coal.

Sections of another coal bed 25 feet higher were obtained at locations 508, 509, 510, 512, and 513. Those at locations 508, 509, and 510 are given on Plate XXXII; the other two are given here:

Section of coal bed at location 512.

Sandstone.	Ft.	in.
Coal.....		6.
Bone.....		1
Coal.....		3
Bone.....		$\frac{1}{2}$
Coal.....	1	3
Coal, impure.....		11
Shale.		
Total section.....	3	$\frac{1}{2}$
Total coal.....	2	11

Section of coal bed at location 513.

Shale, sandy.	Ft.	in.
Bone.....		4
Coal, good.....	1	6
Shale, carbonaceous.		
	1	10

A measurement obtained at location 520, showing 1 foot 6 inches of coal, apparently represents a lens at the same horizon as the bed just described.

An isolated exposure about 1 mile south of Black Lake, at location 529, shows 8 inches of impure coal. The surface of the divide is very flat, and owing to the great amount of wind-blown sand drainage is imperfect and natural reservoirs have been formed in several places. By the use of short dirt dams the Indians have been able to conserve in these reservoirs a considerable supply of water.

MEYERS CREEK.

Meyers Creek has cut a rather sharp valley into the plain to a depth of about 100 feet. In this valley the Fruitland formation is well exposed. The dip of the beds is N. 15° E., about 100 feet to the mile.

Five coal horizons are recognized on upper Meyers Creek (see Pl. XXXIV), all of little value because of partings and variability. At two of these horizons there are poor, lenticular beds; the beds at the other three vary much laterally and are everywhere split by many thin partings of shale and bone. The lowest coal bed of

the Fruitland formation lies immediately on the Pictured Cliffs sandstone and was measured at locations 535, 537, 539, and 544. This bed is thin and variable, as shown by the following sections:

Section of coal bed at location 535.

Shale, carbonaceous.	Ft.	in.
Coal		11
Shale, carbonaceous.....		4
Coal, impure.....		4
Shale, carbonaceous.		
	1	7

Section of coal bed at location 537.

Shale, carbonaceous, black.	Ft.	in.
Coal		7
Shale	1	5
Coal, impure.....		6
Sandstone, gray.		
	2	6

Section of coal bed at location 539.

Shale, carbonaceous, black.	Ft.	in.
Coal, impure.....		4
Sandstone, yellow.		

Section of coal bed at location 544.

Shale, carbonaceous, black.	Ft.	in.
Coal		5
Sandstone.....		1
Coal, impure.....	1	5
Shale		2
Coal	1	2
Sandstone.		
	3	8

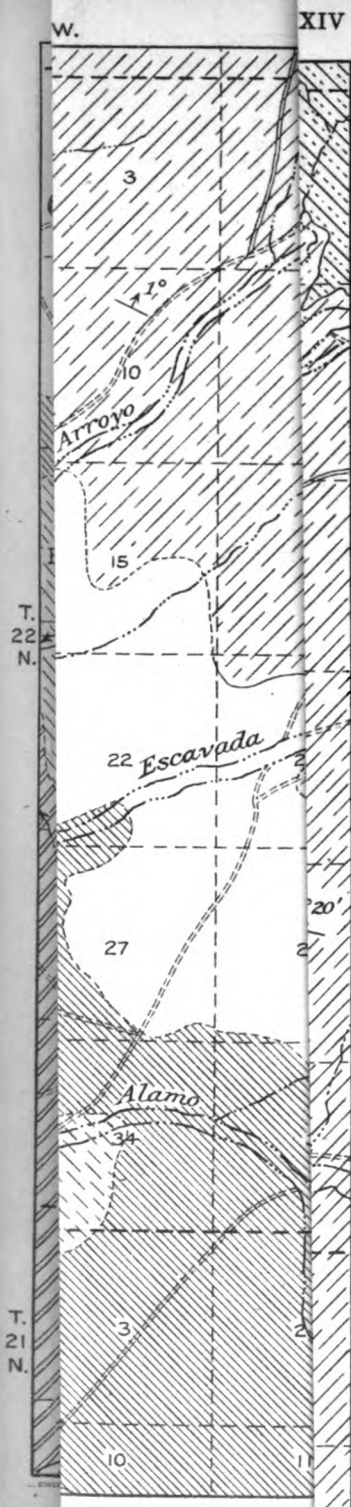
About 6 feet above this bed a short lens at location 536 shows 3 inches of coal.

The second coal bed is separated from the lowest one by 40 feet of sandy shale and was measured at locations 532, 534, 538, 542, 543, and 545. As shown by these sections, which are all given on Plate XXXII, the bed averages more than 5 feet in thickness, though it is split by many thin partings of shale and bone, and many of the benches of coal are impure.

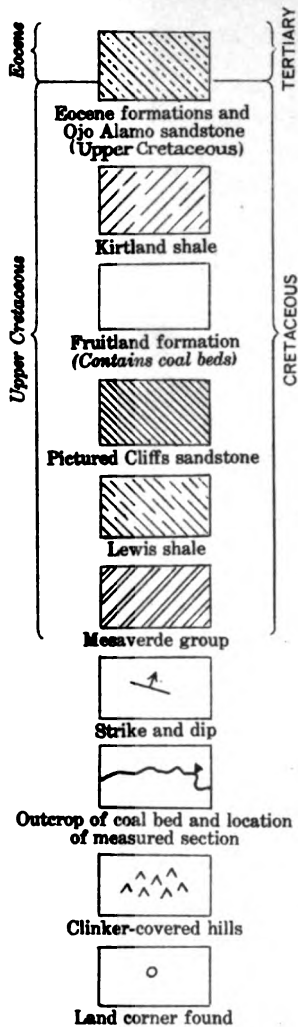
On the south fork of Meyers Creek a bed of coal comes in 15 feet above the one just described, and a section of it was obtained at location 546.

Section of coal bed at location 546.

Shale, carbonaceous.	Ft.	in.
Coal	1	
Shale, carbonaceous, black.....		8
Coal, impure.....	1	2
Shale, carbonaceous.		
	2	10



EXPLANATION



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A higher coal bed occurs on the south fork of Meyers Creek 15 to 20 feet above the lens just mentioned and also crops out on the north fork. Measurements of it were obtained at locations 530, 533, 540, and 541. This bed averages about 6 feet in total thickness but is split into many benches by partings of shale, sandstone, and bone. The section at location 533 is given below; the other measurements are given on Plate XXXII.

Section of coal bed at location 533.

	Ft.	in.
Shale, brown.		
Coal, impure.....	1	3
Shale, carbonaceous, black.....		3
Bone.....	1	4
Shale, carbonaceous, black.		
	2	10

A bed of coal 10 feet higher than the one last mentioned was measured at location 547. It is very thin north of this point but may continue for some distance to the southeast. The section is given on Plate XXXII.

BRANCHES OF ESCAVADA WASH.

The Fruitland formation is fairly well exposed on Kimbetoh Arroyo and Alamo Arroyo but less so on Escavada Wash. (See Pl. XXXIV.) On these arroyos considerable burning has occurred, particularly north of Kimbetoh Arroyo, and the resulting clinker is heavy enough to suggest the presence of thick beds of good coal. However, only thin lenticular beds with many partings are exposed. The visible variation laterally in the coal beds and the inclosing shale and sandstone is so great in even short exposures that there is little justification for attempting correlations between them where the concealed intervals are large.

On a small arroyo branching northeastward from Kimbetoh Arroyo two beds of coal are exposed. A nearly complete section of the lower bed, which rests on the Pictured Cliffs sandstone, measured at location 551, is as follows:

Section of coal bed at location 551.

	Ft.	in.
Shale, carbonaceous.		
Coal, with resin.....		9
Shale, black, carbonaceous.....		3
Coal, with resin.....		10
Bone, sandy.....		3
Coal, with resin.....	1	4+
Total section.....	3	5+
Total coal.....	2	11+

Ten feet above this bed, at location 550, the second bed was measured, as follows:

Section of coal bed at location 550.

Shale, carbonaceous.	Ft.	in.
Coal		7
Shale, carbonaceous.....		2
Coal, with resin.....	1	7
Shale, carbonaceous.....		6
Coal		9
Shale, carbonaceous.		
Total section.....	3	7
Total coal.....	2	11

North of Kimbetoh Arroyo much clinker occurs and there are three horizons at which coal is exposed. The lowest bed rests on the Pictured Cliffs sandstone, and a section measured at location 556 is given below. At 20 feet above this bed occurs another lens which was measured at locations 553, 554, and 555. At 10 feet above this second lens is a stratum of baked rock thick enough to suggest the presence of much more coal than that which shows at the only point available for a section of the bed (location 552). These sections are given below:

Section of coal bed at location 556.

Sandstone, carbonaceous.	Ft.	in.
Coal, with resin.....	1	6
Shale, carbonaceous.....		6
Sandstone, Pictured Cliffs.		
	2	

Section of coal bed at location 553.

Shale, carbonaceous.	Ft.	in.
Bone.....		4
Coal		3
Bone.....		6
Bone, very sandy.....		3
Coal, with resin.....	1	9
Bone.....		2
Coal		6
Shale, carbonaceous.		
Total section.....	3	9
Total coal.....	2	6

Section of coal bed at location 554.

Shale, sandy.	Ft.	in.
Coal, with resin.....		10
Bone, with resin.....	1	8
Coal, with resin.....	1	8
Shale, carbonaceous.		
Total section.....	4	2
Total coal.....	2	6

Section of coal bed at location 555.

Shale, carbonaceous.	Ft.	in.
Coal, with resin-----	1	2
Bone, with resin-----		1
Coal, with resin-----		5
Shale, carbonaceous.		
Total section-----	1	8
Total coal-----	1	7

Section of coal bed at location 552.

Shale, carbonaceous.	Ft.	in.
Bone, with resin-----	1	4
Sandstone, carbonaceous-----		3
Shale, carbonaceous-----		3
Coal, with resin-----		8
Bone, with resin-----		8
Shale, carbonaceous.		
Total section-----	3	2
Total coal-----		8

On the south side of Kimbetoh Arroyo exposures are poor, but some clinker shows and a small bed of coal was measured at location 557. The horizon is about 12 feet above the top of the Pictured Cliffs sandstone.

Section of coal bed measured at location 557.

Shale, carbonaceous.	Ft.	in.
Coal, containing resin-----	1	2
Shale, carbonaceous-----		2
Coal, containing resin-----	1	2
Shale, carbonaceous.		
Total section-----	2	5
Total coal-----	2	4

Between Escavada Wash and Alamo Arroyo there are several small nameless arroyos branching northeastward from Alamo Arroyo. These have eroded extensive badlands, exposing the Fruitland and Kirtland formations, and all the coal present in the Fruitland is visible or indicated by burns. There is evidence of only two coal horizons—one near the base and the other near the top of the Fruitland—neither of which extends very far laterally. The lower coal is exposed in an outlier and was measured at locations 560 and 561, about 1,000 feet apart horizontally. The upper coal was measured at locations 558 and 559.

Section of coal bed at location 560.

Shale, carbonaceous.	Ft.	in.
Coal, containing resin-----	1	10
Shale, carbonaceous-----	2	2
Coal, containing resin-----	1	7

	Ft.	in.
Shale, carbonaceous.....		1
Coal, containing resin.....	2	8
Shale, carbonaceous.....		
Total section.....	8	4
Total coal.....	6	1

Section of coal bed at location 561.

	Ft.	in.
Shale, carbonaceous.....		
Coal, containing resin and some shale laminae.....	1	10
Shale, carbonaceous.....	1	5
Coal, containing resin.....	1	9
Shale, carbonaceous.....		
Total section.....	5	
Total coal.....	3	7

Section of coal bed at location 558.

	Ft.	in.
Shale, carbonaceous.....		
Coal, high in ash.....		6
Bone.....		6
Coal, containing resin.....		5
Shale, carbonaceous.....		6
Coal, high in ash.....		6
Shale, carbonaceous.....		
Total section.....	2	5
Total coal.....	1	5

Section of coal bed at location 559.

	Ft.	in.
Shale, carbonaceous.....		
Coal, containing resin.....	1	4
Bone.....		6
Coal, containing resin.....		6
Sandstone, carbonaceous.....		3
Coal, containing resin.....		9
Shale, carbonaceous.....		
Total section.....	3	8
Total coal.....	2	11

On the north side of Alamo Arroyo a short exposure of a single bed of coal in the upper part of the Fruitland formation was measured at locations 562, 563, and 564. This bed is split by many shale partings, as is shown on Plate XXXII.

On the south side of Alamo Arroyo another exposure of a single bed at very nearly the same horizon was measured at locations 565, 566, 567, and 568. These sections also show many partings. (See Pl. XXXII.)

The lower part of the Fruitland formation is largely concealed in Alamo Arroyo, but baked rock shows the former presence of some coal.

A reconnaissance of the area underlain by the Fruitland formation 7 or 8 miles southeastward from Alamo Arroyo furnished little evidence of coal. Much of the area is covered, but where exposures are available very little coal is seen.

SOUTHEAST OF ESCAVADA WASH, IN MCKINLEY COUNTY.

An inspection of the maps and sections of coal beds shows that in the Hunter Wash district the coal beds have more partings than those farther west and north. From the Hunter Wash district southeastward the coal beds progressively decrease in number, extent, and thickness, and the coal deteriorates in quality. There are fewer and less valuable beds in Black Lake Canyon than in Coal Creek; fewer in Meyers Creek than in Black Lake Canyon. In the Escavada Wash district only thin scattered lenses of impure coal are present. This very noticeable deterioration probably continues for some distance beyond the limit of the field considered in this paper, and the presence of valuable coal beds to the southeast in the Fruitland formation is very unlikely, though such beds have been reported to occur within the next 25 miles by Shaler and Gardner,¹⁹ who made a rapid reconnaissance of the district. At a number of other places where this preliminary work records the presence of valuable coal beds the detailed survey has failed to find them or has shown that they really are so filled with partings as to have only small value, and it is possible that this is true also in the districts not yet surveyed in detail. Gardner²⁰ reports that east of R. 5 W. the Fruitland formation (his Laramie formation) is barren of coal.

¹⁹ Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal fields of Colorado and New Mexico: U. S. Geol. Survey Bull. 316, pp. 376-426, 1907. Gardner, J. H., The coal fields between Gallina and Raton Spring, N. Mex., in the San Juan coal region: U. S. Geol. Survey Bull. 341, pp. 335-351, 1909.

²⁰ Gardner, J. H., op. cit., p. 347.

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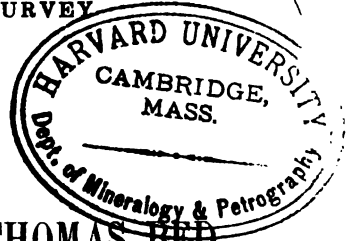
DEPARTMENT OF THE INTERIOR

JOHN BARTON PAYNE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 716—H



**CHARACTER OF COAL IN THE THOMAS BED
NEAR HARRISON, WEST VIRGINIA**

BY

MARIUS R. CAMPBELL

**Contributions to economic geology, 1920, Part II
(Pages 239-241)**

Published February 18, 1921



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1921**

CHARACTER OF COAL IN THE THOMAS BED NEAR HARRISON, WEST VIRGINIA.

By MARIUS R. CAMPBELL.

In a report recently issued by the United States Geological Survey ¹ the coal of the Oakmont mine, on Abram Creek, 1 mile southeast of Harrison, W. Va., was reported, on the basis of a single analysis, to contain 2.95 per cent of sulphur. On receiving a protest from the owners of the mine that this percentage is entirely too great and that the publication of this figure would tend to discredit the coal in the market, the mine was visited on July 15, 1920, by the writer, and new mine samples for analysis were cut. These represent the coal in the parts of the mine from which most of the coal is now being mined or from which production is expected in the near future. The analyses of the samples, together with that published previously (No. 69071), are as follows:

Analyses of coal from the Oakmont mine, near Harrison, W. Va.

	75355	75356	75357	69071
Moisture.....	2.3	1.8	2.1	2.4
Volatile matter.....	16.3	16.6	16.6	15.4
Fixed carbon.....	73.2	71.1	71.2	71.8
Ash.....	8.2	10.5	10.1	10.4
Sulphur.....	1.01	1.56	2.78	2.95
British thermal units.....	14,040	13,490	13,620	13,420

Sample 75355 was cut at the face of the first right entry, about 2,500 feet from the mine mouth; sample 75356 at the face of the seventh left entry, 300 feet from the main entry and about 4,000 feet from the mine mouth; sample 75357 in room 19, off the twelfth right entry, 1,000 feet from the main entry and about 5,000 feet from the mine mouth; and sample 69071 in room 11, off the thirteenth right entry, 5,100 feet from the mine mouth.

¹Ashley, G. H., The Abram Creek-Stony River coal field, northeastern West Virginia: U. S. Geol. Survey Bull. 711, pp. 85-103, 1920.

The sections of the coal bed at the points sampled and the parts included in the samples are as follows:

Sections of Thomas coal bed in Oakmont mine, near Harrison, W. Va., showing parts sampled.

75355.		Ft.	in.	75357.		Ft.	in.
Bone.....	..	1		Coal ²	..	9½	
Coal ²	1	2½		Bone and coal.....	1	2½	
Bone.....	..	2		Coal ²	2	9½	
Coal ²	2	9½		Total coal.....	3	6½	
Total coal.....	4	0		Bed.....	4	9	
Bed.....	4	3					
75356.		Ft.	in.	69071.		Ft.	in.
Coal ²	..	11		Coal ²	..	11	
Bone and coal.....	..	10½		Shale.....	..	1½	
Coal ²	2	9		Coal ²	..	5½	
Total coal.....	3	8		Bone.....	..	5	
Bed.....	4	6½		Coal ²	2	7	
				Total coal.....	3	11½	
				Bed.....	4	6	

From these analyses it is apparent that the coal of the Oakmont mine is a semibituminous or smokeless coal, which is rather high in ash and contains a variable amount of sulphur. The analyses show that the coal with the lowest percentage of sulphur (1.01 per cent) is within half a mile of the mouth of the mine; that the sulphur content increases with considerable regularity to 1.58 per cent at a point about 4,000 feet from the mine mouth, 2.78 per cent about 5,000 feet from the mine mouth, and 2.95 per cent about 5,100 feet from the mine mouth. A short distance beyond the point last mentioned the main entry of the mine has been driven through to the outcrop of the coal bed on the south side of the spur of the hill which projects from the west into the bend of Abram Creek at Emoryville. On account of this limitation of the mine in a southerly direction it is not known whether the sulphur continues to increase in that direction or whether the high-sulphur coal is limited to a certain area and is succeeded by coal of a lower sulphur content than that showing in the southern part of the mine.

In the recent sampling the writer was accompanied by the mine foreman, who, at each place where a sample was cut, indicated the parts of the coal bed that were excluded in mining, and these parts were carefully excluded from the sample cut for analysis. At the point where sample 75355 was taken only two small layers of bone were excluded, but where samples 75356 and 75357 were cut the middle member of the bed consists of an intimate mixture of bone

² Part sampled.

and coal, some of which is "gobbed" by the miners but most of which is loaded on the mine cars and is supposed to be thrown out when the coal passes from the screens into the railroad car. Much of the bone is thus doubtless removed, but some of it escapes the pickers, and hence it is probable that the coal which reaches the market contains a higher percentage of ash than is shown in the analyses given above.

The main entry of the mine is driven on the coal bed, which dips gently northward, at an angle sufficient for drainage of the mine by gravity. At the time of sampling the superintendent stated that the daily output of the mine was about 450 tons.

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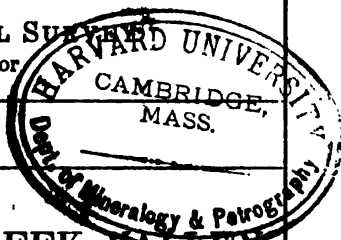
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**GEOLOGY OF ALAMOSA CREEK VALLEY
SOCORRO COUNTY, NEW MEXICO**

**WITH SPECIAL REFERENCE TO THE
OCCURRENCE OF OIL AND GAS**

BY

DEAN E. WINCHESTER

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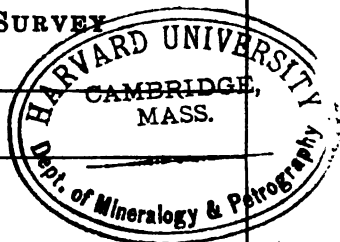
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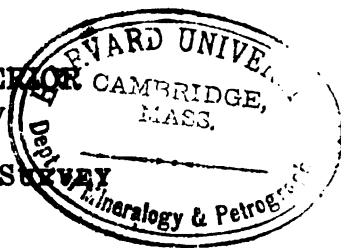
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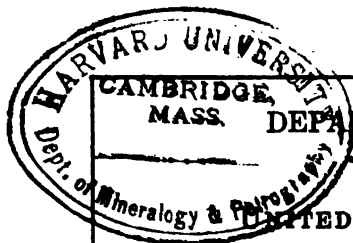
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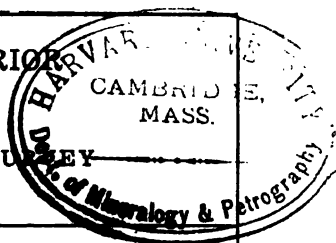
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BULLETIN 716—G

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SAN JUAN COUNTY, NEW MEXICO

BY

CLYDE MAX. BAUER

AND

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